The Smart City level of the City of Tshwane compared to the European city standard, and its contribution towards the city's environmental sustainability.

by

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ABSTRACT

The overall objective of the study is to plan and recommend the most appropriate city environment that can foster the dynamic interactions necessary to implement sustainable and adaptable smart city projects for the purpose of enhancing the quality of the natural environment. Specific research approaches have been applied to answer the separate research questions, which is a performance indicator approach combined with a literature review. The Smart City level of Tshwane is measured, and it is further analysed how this contributes towards environmental sustainability on a city level. Even though environmental issues persist in the City of Tshwane, it was observed that there exists a direct correlation between smart city implementations and the improvement of environmental sustainability, from international examples. It is thus evident from the study that smart city initiatives applied in all city activities facilitate the enhancement of resource efficiency within a city. This ultimately contributes to improving the environmental performance, quality, liveability and sustainability within the cityscape. In order to achieve this, the Smart City level of a city needs to be measured and evaluated to establish a baseline supported by existing data to best inform an integrated approach in planning and implementation procedures (Bosch, et al., 2017). Smart city technologies and implementations create the setting for possible significant changes towards environmental sustainability.

Key Terms: City of Tshwane, Smart City, ICT, environmental sustainability, environmental performance, evaluation, *EUROCITIES CITYkeys*' Key Performance Indicator Framework, Key Performance Indicators, city-level, and literature review.

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LIST OF ACRONYMS

ARC	Agricultural Research Council
AVL	Automatic Vehicle Location
BEPP	Built Environment Performance Plan
COT	City of Tshwane
CSIR	Council for Scientific and Industrial Research
EBRD	Bank for Reconstruction and Development of Europe
ESN	Environmental Sensor Network
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIS	Geographic Information System
GLOSA	Green Wave Optimization Mobile Application
GPS	Global Positioning System
HSRC	Human Science Research Council
ICT	Information and Communications Technology
IDP	Integrated Development Plan
IDRC	International Development Research Centre
IESE	Improvement and Efficiency Social Enterprise
IoT	Internet of Things
IR4	Fourth Industrial Revolution
ISO	International Organization for Standardization
ITS	Intelligent Transportation System
IUDF	Integrated Urban Development Framework
KPI(s)	Key Performance Indicator(s)
LEED	Leadership in Energy and Environmental Development
MDG(s)	Millennium Development Goal(s)
MRI	Medical Research Institute
NEMA	South Africa National Environmental Management Act
NERSA	National Energy Regulator of South Africa
NRF	National Research Foundation

OOC	Orlando Operations Centre
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis approach
SACN	South African Cities Network
SDF	Spatial Development Framework
SDG(s)	Sustainable Development Goal(s)
SONA	State of the Nation Address
SPLUMA	Spatial Planning and Land Use Management Act
TOD(s)	Transit Oriented Development(s)
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WCCD	World Council on City Data
WESSA	Wildlife and Environment Society of South Africa
WHO	World Health Organisation

1. CHAPTER ONE: GENERAL OVERVIEW

1.1 Introduction

A number of definitions are associated with the “Smart City” concept, dependant on the interpretation of the word “Smart” - for example a ubiquitous city, intelligent city or a sustainable city (Albino, et al., 2015). The study presented here focuses on the effects of smart city initiatives and technological advancements on a city’s environmental sustainability and sensibility. The description of a Smart City most appropriate to be applied to the study is thus, from Setis-Eu (2012, as cited in Singh & Kumar, 2017, p. 232*) - “A Smart City is a city in which it can combine technologies as diverse as water recycling, advanced energy grids and mobile communications in order to reduce environmental impact and to offer its citizens better lives.”* The smart city concept is thus interpreted as providing initiatives that increase the quality of the environment within the city. The smart city concept is relatively new in South Africa, and requires trans- and inter- disciplinary approaches to achieve a sustainable city in practice.

It has been emphasized by Toppeta (2010) that smart city implementations increase sustainability and improve liveability of the city. Smart Cities combine diverse technological implementations for the purpose of reducing environmental impacts, whilst contributing to improve the wellbeing of citizens (Kushida & Zysman, 2009). A smart environment may include; smart renewable energy generation, pollution control, sustainable energy grids enabled by ICT and smart monitoring systems to improve sustainability (Okay, 2016).

Today, a range of environmental challenges are present in the City of Tshwane which include waste management, environmental pollution, lack of green infrastructure and access to safe potable water (Silva, et al., 2018). The study area thus provides the opportunity to evaluate and compare performances, and propose interventions (Pacione, 1990). Certain aspects of a Smart City are present within the City of Tshwane, and such elements may thus be measured and evaluated to exploit opportunities, specifically regarding the contributions towards environmental quality (Singh & Kumar, 2017). Consequently, the City of Tshwane plays a significant part in the Smart City Movement of South Africa.

1.2 Problem statement

Over the past few years, the idea of Smart Cities has obtained significant attention globally (Giffinger, et al., 2007). African cities are facing challenges and delivering services at an unsustainable rate due to increasing unplanned urbanisation of societies (SACN, 2016). The City of Tshwane has been developing unsustainably, largely due to the typical resource-intensive development path followed and the lack of adequate monitoring systems -

inefficiencies are thus present across sectors (City of Thwane, 2018). It is therefore crucial that the Smart City level of Tshwane is measured and compared to international standards to gain knowledge on the topic and to contribute towards environmental health, international competiveness and human wellbeing. The research questions addressed here thus need to identify all key aspects that play a role in this specific research environment. Therefore, the research questions are structured as follows;

1. How does the City of Tshwane compare to the Smart City measure of European Cities?

2. Does the measured Smart City level of Tshwane contribute towards the city's environmental sustainability, and if so how?

1.3 Background and rationale for study

A range of environmental challenges are increasingly present in cityscapes, which include (but are not limited to) waste management, environmental pollution, lack of green infrastructure and safe potable water (Silva, et al., 2018). The smart city concept is interconnected with that of a green city, sustainable city, or eco-city. The concept of a 'smart environment' may include (amongst others); smart renewable energy generation, pollution control, sustainable energy grids enabled by ICT and smart monitoring systems to improve sustainability (Okay, 2016).

The study was applied to the City of Tshwane, in an endeavour to explore the environmental sustainability of the City of Tshwane and to provide recommendations, while considering general limitations and the scope of the dissertation. Observably, the City of Tshwane is not currently performing at its fullest environmental potential (Lucas, 2011). Some examples of this observation includes the lack of water leakage detection, measurement and management and the inefficient recapturing of storm water via attenuation and seepage wetlands to replenish underground sources prior to its loss to rivers (SACN, 2016). Furthermore, reducing the peak demand of electricity, harvesting of fallout and water for purification regarding sewer services, ineffective monitoring of citizen wellness, which includes health, safety and security (SACN, 2014). Lastly, the City of Tshwane's transportation systems are unsustainable, specifically referring to its contribution to the global pollution rates. The study area thus provides the opportunity to evaluate and compare performances and propose interventions (Pacione, 1990).

The rationale for the study area further takes into account the fact that the City of Tshwane is the administrative centre of South Africa, certain sectors of the city economy are thriving, and the City is adapting relatively well to globalisation (SACN, 2016). Some features of a Smart City are

present within the City of Tshwane, and such elements may thus be measured and evaluated to exploit opportunities, specifically regarding the contributions towards environmental quality (Singh & Kumar, 2017). Elements include the utilisation of alternative energy systems, a built environment that takes into account the City's environmental sensitivity, well-known initiatives for waste management and water conservation, and the majority of people with the correct attitudes regarding recycle and re-use opportunities (City of Tshwane, 2013).

1.4 Research objectives

Specific research approaches have been applied to answer the separate questions, which are the use of the *EUROCITIES CITYkeys*' Key Performance Indicators as Smart City level measurement, and the contributions towards environmental sustainability on a city level that is assessed through an extensive literature review. The Key Performance Indicators are quantifiable measurements for a cityscape and the literature review approach includes the study of peer reviewed articles and municipal documents, combined with a deductive approach (Darke, et al., 1998).

The research objectives identify, describe and assess the following;

1. How does the City of Tshwane compare to the Smart City measure of European Cities

    a. Through the application of the *EUROCITIES CITYkeys*' Key Performance Indicators, the development and validation of a transparent performance evaluation framework for the City of Tshwane could be established.
    b. By endorsing the integration and application of the performance system within the city's decision-making processes.
    c. By providing a platform for the engagement of stakeholders in identifying and exploiting opportunities for the City of Tshwane.
    d. The ultimate objective when applying the *CITYkeys* indicators is to promote rapid widespread adoption and implementation of smart city services and solutions in order to achieve sustainable environmental goals within urban areas.

2. Does the measured Smart City level of Tshwane contribute towards the city's environmental sustainability, and if so how?

a. Establishing the relationship between key smart city indicators and environmental performance, which are to be applied to measure progress and achieving policy objectives.
b. Indicating a way forward, application of smart city ideas to be adopted for the objective of enhancing the quality of the environment in the long-run, to achieve environmental sustainability.

Accordingly, the overall objective is to plan and recommend the most appropriate city environment that can foster the dynamic interactions necessary to implement sustainable and adaptable smart city projects for the purpose of enhancing the performance of the natural environment.

1.5 Research layout

The research report is divided into five chapters, each formulated to answer the research questions in turn. Firstly, an in-depth literature review was conducted for the purpose of gaining knowledge on the research topic and also to formulate an adequate synthesis of the study. A range of themes are discussed in the literature review to create a strong structure and study focus (Christiaanse & Höger, 2006). The literature that was studied is categorised into two different themes - Smart Cities and Environmental Sustainability. The two different themes were then linked together into the general theme of the study - namely the City of Tshwane's Smart City level compared to international standards, including the way in which this contributes to the city's environmental sustainability. The study provides motive for integrating the two themes and refers to international examples, implications and solutions, and the future planning repercussions of the City of Tshwane.

The methodology is presented through explaining the design of the research approaches, the study rationale, and the specific study area and research types in Chapter 3. The two different research approaches are described separately and, subsequently, associations are identified and explained. First, a comparative research approach is followed regarding the Smart City level of the urban spaces of the City of Tshwane and the chosen European city standard, due to the fact that the approach provides better insights concerning a performance based analysis. Once the Smart City level has been measured according to the Key Performance Indicators of the *EUROCITIES CITYkeys*, a basis of progress and smart city initiatives are provided, thus making it possible to adequately compare the cities with one another. City-level indicators according to the *EUROCITIES CITYkeys* may be applied to compare cities with one another, and these comparisons are carefully considered (Bosch, et al., 2017). The use of different research

methods is referred to as triangulation, and is utilised to validate findings. After the smart city indicators were applied and measured to compare the international examples with the national, the study continues to identify how this contributes towards the environmental sustainability of the city. The environmental sustainability contributions were assessed according to standards acquired from various peer reviewed literature studies.

The final chapters are dedicated to the application of the two different research approaches, and therefore also the research findings and results. Chapter 4 and Chapter 5 separately present the results, and how they were obtained through application of the two different approaches, to better answer the two research questions. Chapter 4 is specifically dedicated to the Europe standard of the *CITYkeys* Key Performance Indicator applied to the City of Tshwane as the Smart City level measurement. Selected indicators are further described in detail in Appendix A, including the way in which they were collected and calculated, to better understand the measured results of the City of Tshwane. The chapter is concluded with a discussion on the significance of the approach and the attained results. Chapter 5 presents the results and findings gathered during the systematic review of literature. The purpose of the findings is described, by linking the concept with the Smart City level of Tshwane. The reviewed literature informs the study's conclusion and the discussion of results are presented in the chapter.

The final chapter provides a conclusion, recommendations and interventions for the most appropriate city environment that can foster the dynamic interactions necessary to implement sustainable and adaptable smart city projects for the purpose of enhancing the quality of the natural environment. The two different research approach findings are not separated from one another - in contrast they benefit and build on one another. The technique of triangulation facilitates the validation of data, via cross verification from different sources (Myers & Avison, 2002). The final chapter thus provides recommendations and a final conclusion.

2. CHAPTER TWO: LITERATURE REVIEW

2.1 Environmental sustainable cities

With reference to this study, the word "environmental" is exclusively used in reference to human relations with the ecosystem, unless stated otherwise. John Morelli (2011) more specifically defines environmental sustainability as – *"a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity".* Bedřich Moldan et al. (2012), states that environmental sustainability is appropriately defined when emphasizing its bio-geophysical features, which means improving or maintaining the integrity of the planet's life supporting system. Thus, the concept of sustainability needs to be regarded as more precise specifications in comparison to a vague and mostly qualitative notion.

The "environmental sustainability" working definition for this study was acquired from the book; Our Common Future by the Brundtland Commission, which defines the concept as -*"meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them"* (1987, p. 124). The definition is best suited for this study, because it guides two essentialities. Firstly, key significance is provided to meet the vital needs of both current and future generations through responsible development. Secondly, extreme caution is raised concerning environmental resource depletion, to provide for future generations from natural ecosystems. The report has had a major impact on subsequent initiatives across the globe towards sustainable development.

The Rio+20 United Nations Conference on Sustainable Development, which was in 2012, brought about a motivated political outcome document that contained practical and clear methods for developmental implementations that are sustainable (Rio+20, 2012). Member states also established the Sustainable Development Goals (SDGs), which were built on the Millennium Development Goals[1]. Thus, one should also consider the importance of the innovative guidelines on green economy policies that were adopted by the Conference. The Conference further led to governments agreeing on the topic to support the United Nations Environment Programme (UNEP) on various fronts (2012). However in the face of progress, the Fronesys group states that the Rio+20 United Nations Conference and report might already be at the receiving end of diminished expectations, regarding the actual commitment of global heads of states (Fronesys, 2012). Where some have committed to the UN agreement on

[1] To eradicate extreme poverty and hunger; to achieve universal primary education; to promote gender equality and empower women; to reduce child mortality; to improve maternal health; to combat HIV/AIDS, malaria, and other diseases; to ensure environmental sustainability; and to develop a global partnership for development.

sustainability reporting, seventy-five percent of more than 20 000 companies globally do not report sustainability impacts (Bloomberg, 2012). Therefore, the impacts have a minimal effect on practices of incorporating sustainability data into company valuation.

The 20th century has been characterised by rapid urban development, which often lacks adequate management in most cases, and leads to the development of highly dispersed cities in comparison to the 19th century cities, which were more compact (OECD, 2013). New technological inventions, fast industrialisation, and the availability of inexpensive fossil fuels and cheap land have been driving forces of this rapid urbanisation (Lehmann, 2011). The dispersed city model is highly reliant on the use of fossil fuels and automobiles. Increases in transport and related infrastructures consequently contribute towards the depletion of the natural environmental performance within a cityscape, due to increased impermeable surfaces and city footprints, destruction of green fields and urban natural resources, reduced water quantity and quality, and increased traffic congestion, journey time, and fuel consumption (OECD, 2013). The current urban development movement motivates urban managers, environmental planners and academics to identify innovative methods to encourage urban and socio-economic growth with the minimal environmental effect and sustainable natural resources use. A range of concepts, theories, methods, and reports have been and are produced to address this issue. It was demonstrated by “Our Common Future” that it is possible to bring together social development, economic growth and environmental conservation (WCED, 1987) and the New Urbanism Movement supported more environmentally friendly urban planning practices to limit dispersed city expansion, for example Transit Oriented Developments (TODs) and mixed land use or walkable neighbourhoods (Lehmann, 2011). In the 1990s, the theory of sustainability integrated economic growth, social equity and environmental preservation concerning city development (Campbell, 1996). This created the foundation for other concepts to develop - for instance Liveable City, Sustainable City, Compact City, Green Urbanism and the Smart City, on which this study will specifically focused on (National Research Council, 2002). Many of these concepts are current and at the centre of debates regarding the influences of city designs, urban forms, utilisation of natural resources, built infrastructure, energy and other related issues associated with city and environmental sustainability (Economist Intelligence Unit, 2017).

Ogenis Brilhante and Jannes Klaas indicate in their journal article - “Green City Concept and a Method to Measure Green City Performance over Time Applied to Fifty Cities Globally, (2018)“ - that a city with significant environmental performance increases its sustainable and liveability. It is also shown that population size influences environmental performance within a city negatively, gross domestic product (GDP) influences it positively and air quality and sanitation sectors effects the city’s environmental performance the most (Derkzen, et al., 2015). The existence of

wide-ranging urban and environmental interrelated issues within cityscapes has led to the formulation of numerous urban environmental and innovative city definitions or approaches, as mentioned above. Challenges have thus arisen specifically concerning adoption and acceptability. Some emphasize only the environmental aspects, others also include infrastructure, environmental and socio-economic elements, whilst some include resilience, policies, plans and ICT technologies (Campbell, 1996).

When we refer to environmental sustainability within a South African context, it is essential to include the tools provided by the Green Book (CSIR, 2019). The objective of the Green Book is to deliver adequate climate change adaption actions, with integration and implementation guidelines, for all South African settlements, established according to their distinct risk profiles. The project was conducted from March 2016 to March 2019, and is funded by the CSIR and IDRC thematic funding. The comprehensive intention of the project is to provide local governments a strong scientific evidence base for the purpose of long-term planning and decision-making. The Green Book mostly emphasizes the aspects of resilience, policies and plans, urbanisation and climate change; aspects which will be mentioned and briefly discussed within this specific study. However, the Green Book has only been used as a primary guide for the study at hand, whilst we will be specifically focusing on Smart Cities concerning the *EUROCITIES CITYkeys* definitions and measures and the natural environment's sustainability within an urban space.

2.2 Smart city contribution towards environmental sustainability

Concerning the study at hand and this specific section, the term 'environmental' could be described as the manner in which green and renewable resources are utilised within the natural, built and urban infrastructure of a Smart City with the main purpose of improving environmental sustainability. With regards to resource flows and climate change, natural resource insecurity and extreme weather events amplify challenges of the city, attempting to deliver services to growing population numbers. Due to increasing environmental threats, cities need to develop local resilience, for example resource and energy security. While at the same time negotiating international and regional partnerships to manage and mitigate potential future impacts of climate change and environmental depletion (SACN, 2016). It is recommended that the research model be embraced and applied in a variety of policies that are relevant to smart paradigms, which promote environmental sustainability and green city economies. Worldwide sustainability challenges are addressed through the paradigms at a local context. Smart technological advancements establish new opportunities for various smart city regeneration and development

programmes formulated to address social and environmental challenges located within cities (Ryser, 2014).

Sotiris Zygiaris (2012) describes a “Smart City” as the intellectual capability to address different advanced socio-economic and socio-technical features of development, which thus leads to the smart city conceptions of being “green”, in relation to urban infrastructure implemented for environmental conservation, waste management and decrease of carbon dioxide emissions. Therefore, the environmental aspect of the smart city vision forms part of the bigger purpose to contribute towards significant growth and sustainability, amongst other smart city layers such as social, economic, innovation, integration, instrumentation and interconnectivity (Zygiaris, 2012).

Zygiaris’s conceptual reference framework applies a layered research methodology, for the purpose of describing a smart urban environment (Zygiaris, 2012). For the purpose of this study specific reference is made to the first two layers of the seven layered model, which are the City Layer (Layer 0) and the Green City Layer (Layer 1). Because cities focus on their innovative urban ecosystems from the traditional city point of view, to the innovative “green” and “smart” advantages, to achieve the objective of social and environmental sustainability. The City Layer indicates smart cities are initiated with the “city”, instead of the “smart”, as described by Belissent (2010). Thus, emphasizing that the smart city concept needs to be grounded to the city context. In the town planning sector, cities are rather referred to as “urban or city regions” or even “global city regions”, so as to include the peripheral and even rural areas of the urban conurbation and linkages. However, this study analyses the effects of smart city initiatives within specifically the urban city borders. This study could be further extended to include impacts within rural and city peripheral areas. This was decided by the author due to the tested reference model represented by Zygiaris, who defines the city layer according to the traditional components of a city and is a significant denominator of the position that cities could adopt smart features. In its conventional terms, for every urban space there are certain processes and operations that should be synchronised towards the direction of attaining a smart city’s vision in response to specific constraints (Belisent, 2010). The constraints refer to enhancing a city’s infrastructure interventions and city planning with smart design initiatives, which are intended to complement the Smart City Movement.

The second relevant Layer that was studied is the Green City Layer (Layer 1), and it is inspired by the contemporary urbanisation theories raised by LEED Leadership in Energy and Environmental Development initiatives (2011), and Greenburg (2004). Zygiaris (2012) states – *“A city’s sustainable future is mutually attached to smart city structures”.* Over the past few years, Green Cities have been developing as holistic playgrounds for implementation of a Smart

City towards sustainability. Green City infrastructures generate a productive well-established environment, in which sensors, smart grids and broadband networks lead to innovation and create environmental influence (Greenburg, 2004). Zygiaris (2012) declares that the modernisation of urban planning challenges needs to prioritise environmental sustainable city, which requires innovative systems of policy integration, green governance and financial resource reallocation towards developing and implementing appropriate combination of green urban ecosystems. Policymakers must be confronted with the definition of an environmental sustainable city that includes, but is not limited to, the reduction of the carbon dioxide footprint, together with the city's participation in alternative energy plans. It also needs to be required that the abovementioned policies are formulated in terms of green building specifications and green transport management (LEED, 2011). Zygiaris (2012) refers to the case study of Barcelona, concerning smart city contributions toward environmental sustainability. The city functions under an advanced environmentally focused strategy for the purpose of reducing carbon dioxide levels, and includes transport management, alternative energy, and green building programmes. In Europe, Barcelona is one of the cities with the largest concentration of solar panels implemented (Barcelona, 2011).

The theory illustrates concepts that are applicable to innovative urban ecosystems and green innovation, which are related to issues regarding the Smart City. It further adds to the research motive of establishing that the city is the foundation of smart cities. A city's innovation ecosystems, stakeholders, urban resources, utilities, infrastructure and services includes a triple helix complex. The theory promotes the smart city vision, for the purpose of achieving a sustainable city future and with regards to the bigger picture, a sustainable smart globe. Thus, environmental and city master planning should include innovative features that provides for sustainable, green smart planet development, which is this study's focal point. Lastly, Zygiaris (2012) further discusses the importance of key performance indicators, concerning his conceptual reference model, which should be explored for both sustainability and competitive purposes.

2.3 Defining a Smart City

Zygiaris (2013, p. 217) defines the concept of a "Smart City" as – *"a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green" referring to urban infrastructure for environment protection and reduction of CO_2 emission, "interconnected" related to revolution of broadband economy, "intelligent" declaring the capacity to produce added value information from the processing of city's real-time data from sensors and activators. Whereas the terms*

"innovating", "knowledge" cities interchangeably refer to the city's ability to raise innovation based on knowledgeable and creative human capital."

In recent years, a range of new trends and terminologies have arisen, within the urban and sustainable development fields, including trends such as Information and Communications Technology (ICT) based development, the Fourth Industrial Revolution implementations, and the Smart City Movement (Heddeghem, et al., 2014).

From a range of studies, it is observed that a number of different definitions are applied, often interchangeably, to discuss cities and their spaces, therefore creating confusion concerning the branding of the smart city concept. A range of new names have arisen for cities, for instance Eco-city, Global City, or Smart City (Watson, 2015, p. 36-39). Certain smart city definitions define the city as "smart" once technologies are utilised to address urban problems. For example, Amsterdam's intelligent city lighting, New York's 24/7 programme and the South African National Roads Agency I-traffic project utilises technologies to address urban issues on a project-level (Mirembe, 2017). The term "smart environment" also describes the attractive natural setting (including climate and green space), resource management, pollution and efforts towards environmental preservation (Giffinger, et al., 2007). Thus the term "smart city" is an umbrella concept, which covers numerous subthemes for example smart economy, smart urbanism, smart mobility, smart health, smart technology, smart energy, and sustainable and smart environment (Gudes et al. 2010; Cocchia 2014; Lara et al. 2016).

The study focuses on the Smart City Movement specifically, including its contribution towards a city's environmental sustainability. Elgazzar and El-Gazzar (2017) state that the concept of a smart city is interconnected with that of a Green City, Sustainable City or Eco-city, indicating the strong linkage between the smart city movement and improving the environmental performance of an urban area. Watson (2015, p. 38) further refers to environmental change, ICT and urbanization as an amalgamation that smart cities attempt to manage. The origin of smart cities could be traced back to the well-known 1992 Rio Earth Summit, according to Judith Ryser (2014, p. 447). With regards to this study, we can emphasize the statement made by Cocchia (2014, p. 39), stating that smart cities are characteristically concerned with the environment, environmental change, greenhouse gas emissions, population density management, sanitation, safety and general needs of the public and their wellbeing.

As mentioned previously, a range of environmental challenges are present in cityscapes, which include waste management, environmental pollution, lack of green infrastructure and safe potable water (Silva, et al., 2018). Datta (2015, p. 3) states that Smart Cities are wishful design

and planning approaches to twenty-first century cities that attempt to face the aftermath challenges of urbanization patterns, for example overcrowding, pollution and contamination, which demands improved service delivery. In contradiction, SALGA (2015, p. 9) states that increasing urbanization and population growths essentially creates the need for innovation, for instance developing systems that have the ability to electronically distribute energy or water resources. Mandarano *et al.* (2010) further emphasizes the importance of cities, which experience population growth and high inflows of people, to become Smart Cities.

It has also been specified by Toppeta (2010) that smart city implementations increase sustainability and improves liveability of the city. Smart Cities combine diverse technological implementations for the purpose of reducing environmental impacts, whilst contributing to improve the wellbeing of citizens (Kushida & Zysman, 2009). When referring to a smart environment the following is included; smart renewable energy generation, pollution control, sustainable energy grids enabled by ICT and smart monitoring systems to improve sustainability (Okay, 2016).

Specifically with regards to defining the concept of a 'smart city', the City of Tshwane (2013, p. 113) defines the concept as *"integrating people with capital and infrastructure through technology"*. Therefore, the City of Tshwane envisions by 2055 to increase the quality of life of its residents through smart approaches, by focusing on *"economy, mobility, environment, people, living and governance".*

Looking at a specific working definition; the *EUROCITIES CITYkeys* report ultimately applied and further developed the definition from Neumann *et al.* (2015), which defines a Smart City as - *"a city that efficiently mobilizes and uses available resources (including but not limited to social and cultural capital, financial capital, natural resources, information and technology) for efficiently;*

- *improving the quality of life of its inhabitants, commuting workers and students, and other visitors [people]*
- *significantly improving its resource efficiency, decreasing its pressure on the environment and increasing resiliency [planet]*
- *building an innovation-driven and green economy [prosperity]*
- *fostering a well-developed local democracy [governance]."*

The *CITYkeys'* definition further highlights the aspect of smartness, which are technologies and innovative methods that enable sustainability in different sectors.

2.4 Smart movement threats

Although the majority opinion concerning the smart city and ICT movement, including e-technologies and approaches within the context of the Fourth Industrial Revolution are overall positive, the smart movement also present some threats and challenges that could in turn negatively affect sustainability (Du Plessis & Brandon, 2015). Regarding this study, we focus on the effects smart city initiatives could have on environmental sustainability. There are some negative influences mentioned in peer-reviewed literature, but these effects are minor compared to the positive environmental opportunities. Threats could mostly influence the social and economic paradigms of sustainable development, for example, the over emphasis and concentrated investments towards e-technologies in smart cities, which could lead to peripheral and rural areas being neglected (Marsal-Llacuna, et al., 2015). It is mentioned in this study that smart city initiatives are globally focused on the urban sphere and services taking place only within the cityscape, thus a digital divide is created by excluding areas of the urban region in its entirety. Challenges could arise if smart urban and environmental planners in their efforts, do not strive toward enhancing the relationship between citizens and their environment in such a manner to provide balance to the system. Balance among citizens and the environment includes social equity, environmental justice and other type of equilibria (Stokes, et al., 2015).

Environmental challenges increase and continue affecting citizen health and wellbeing, which in turn affects the economic sector, due to the fast pace nature of urbanisation and industrialisation. Thus, it is vital to keep in mind the negative effects of smart city initiatives and to keep them to a minimum; however it is evident that we need innovative systems to reduce urbanisation repercussions in today's cityscapes. Once smart city initiatives are implemented correctly, with a holistic, equal and all-inclusive approach, the gap between the sustainable use of resources and the development of urban infrastructure could be bridged. This is important to include in development approaches, especially in developing countries. This project focuses on the possible environmental impacts of the Smart City movement and its applications, to provide a way forward for policymakers and relevant framework conditions.

2.5 International smart city measures

In this study, a comparative research approach is applied regarding the Smart City level of the urban spaces of the City of Tshwane, since the approach provides better insights concerning a performance based analysis (Bosch, et al., 2017). The City of Tshwane's Smart City level is compared to the chosen European city standard, specifically the Key Performance Indicators of the *EUROCITIES CITYkeys* (2017).

Internationally, there are a range of performance indicator frameworks, specifically developed to measure the sustainability levels within a cityscape. To name a few;

- **The In-depth Report (12) Indicators for Sustainable Cities (European Comission, 2018),**
  (Sustainability indicator framweorks of the source includes; the EEA Urban Metabolism Framework, European Green Capital Award and the China Urban Sustainability Index)
- **The United Nations Sustainable development goals (2015),**
  (Sustainability indicators of the source includes; climate action, sustainable cities and communities, life on land and affordable and clean energy)
- **The Millennium Development Goals (MDGs) established by WHO (2015),**
  (Sustainability indicators of the source includes; to ensure environmental sustainability, to develop a global partnership for development, and to eradicate extreme poverty and hunger)
- **SEC model for sustainable development tracking (Cafuta, 2015),**
  (Sustainability dimensions of the source includes; suitability to everyone, environmental acceptance and cost effectiveness)
- **The Circles of Sustainability model established by the Global Compact Cities initiative,**
  (Sustainability sectors of the source includes; economic, political, ecological and cultural)
- **The Green City Index (2009),**
  (Sustainability indicators of the source includes; Carbon dioxide emissions, energy, buildings, land use, transport, water and sanitation, waste management, air quality and environmental governance)
- **Conceptual Reference Model (Zygiaris, 2012).**
  (Key performance indicators of sustainability from the source includes; innovation, application, integration, instrumentation, inter-connection, environmental and the city)
- **The Improvement and Efficiency Social Enterprise (IESE) Cities in Motion Index (2015).**
  (Sustainability indicators of the source includes; human capital, social cohesion, economy, public management, governance, environment, mobility and transport, urban planning and technology)

A city's sustainability could be described as the services of a city efficiently delivering outputs to maintain and enhance all city programmes, and quality of life is being maximized for citizens. However for the purpose of this study, emphasis is drawn to specifically measure the smart level

of the case city - in other words the attempt to manage environmental change, environmental performance and urbanization by implementing smart city initiatives on a city-level (Watson, 2015). The view of sustainability, concerning this study, is overall focused on environmental performance and some social aspects, to include the theory of environmental justice. Therefore, it is the opinion of the author that the application of the *EUROCITIES CITYkeys* Key Performance Indicators on city-level is the most applicable framework to adequately measure the City of Tshwane's smart city performance. Benefits of using the specific standard includes the opportunity to compare worldwide cities, findings are supported by specialist and peer backing, and a comprehensive analysis of various indicators of a Smart City is provided. Further, the opportunity to aim for a defined standard is provided, relevant international issues are covered and the opportunity could be realised to enhance the case city's environmental performance through smart city initiatives.

Smart technological advancements establish new opportunities for various smart regeneration and development programmes formulated to address social and environmental challenges located within cities. It is clear that smart city programmes have received plentiful public promotion; there is, however, a lack of discussion concerning evaluating smart programmes and measuring their outcomes on a city and project level. Existing evaluation approaches, such as those mentioned above, are too broad and do not capture the essence of what smart city initiatives can do for a city and its environmental sustainability. Caird et al. (2016, p. 53) criticises some of the evaluation approaches as being inadequate and non-standardised, and focus is drawn more on investment metrics and implementation processes, instead of the effects smart city initiatives have on strategic city development and outcomes. It has been indicated from a number of literature studies, that cities find it challenging to recognise and prove the value of specific smart city activities, interventions and projects - also in turn identifying the fundamental impact on directed city outcomes (Caird, et al., 2016). Globally, the majority of cities have not yet formulated a framework for the measurement and assessment of smart city initiatives on a city scale, even though they are aware of the on-going work regarding the smart city evaluation agenda being driven by EUROCITIES and the British Standards Institution group (Albino, et al., 2015).

It has been recognised by Milton Keynes Council that measuring and developing indicators of growth regarding smart cities have been considerably more attainable than assessing the causal effects on targeted urban outcomes (Caird, et al., 2016). Bosch, et al. (2017) refers to the importance of taking into account the cause-effect relationships concerning smart city initiatives. When studying the case of Birmingham city, it was indicated that authorities struggled to link efforts to city outcomes and accredit the connection to smart city programmes, even though the

baseline measures described progress. The example of Birmingham reflects that the evolutionary-systemic perceptions on the dynamic and complex nature of the city system, and its subsystems, are not limited (Arnold, 2004).

Alternative international smart city measures are indicated above and is noted that the EUROCITIES Key Performance Indicator framework is the most appropriate quantifiable measure for the Tshwane cityscape. Even though there are existing challenges when evaluating the smart performance of a city, the ultimate objective is to promote rapid widespread adoption and implementation of smart city services and solutions in order to achieve sustainable environmental goals within urban areas, for the purpose of this study. The application of the *EUROCITIES CITYkeys*' Key Performance Indicators provides validation and the establishment of a transparent performance evaluation framework for the City of Tshwane.

2.6 Environmental justice

From the abovementioned statements, one might ask why environmental quality needs to be emphasized and why is it so important? In recent years the answer has become increasingly apparent, which is that the issue of environmental quality is inseparably linked to that of social equality at all scales. Access to environmental resources vary due to different human factors, such as level of income, age, disability, ethno-racial characteristics and other forms of differences (Wolcha, et al., 2014).The importance of uneven accessibility of environmental resources in urban areas has led to it being recognised as an matter of environmental justice. US Environmental Protection Agency defines Environmental justice as *"the fair treatment and meaningful involvement of all people, with respect to the development, implementation and enforcement of environmental laws, regulations and policies"* (Laurent, 2011, p. 1847). In addition environmental justice forms an integral part of compliance with legislation, specifically the Spatial Planning and Land Use Management Act (SPLUMA) and that of the Constitution of the Republic of South Africa.

Environmental justice principles link with that of SPLUMA, specifically the principles of equity and justice. For example, the implementation of correct environmental clean-up strategies and greenspace developments could lead to the existing population of the working-class addressing both social and environmental justice. Urban environmental strategies need to be articulated so as to enhance environmental equity, public health, social justice, economic development, and quality of the environment in urban communities. In the context of South Africa, it is recognised that the practice of environmental justice has been reactive - in other words responses to external pressure on communities are not proactive and only add to their disadvantages. It is

necessary that government at local, national and regional scale seek to embed the practical approaches and central principles of environmental justice into sustainable development plans and policy. The theory of environmental justice will be further discussed throughout the study, including how it relates to the research questions at hand.

2.7 International smart city initiatives

2.7.1 Singapore, Republic of Singapore

Smart city initiatives in Singapore derived from the Smart Nation Vision that was implemented in 2014, which strives towards harnessing data, networks and ICT as a measure of mitigation for increasing urban challenges that include urban density, aging population and natural resource sustainability (Lee, et al., 2016). Singapore's smart initiatives could have been expected to be highly advanced, due to their legendary infrastructure, quality of human capital and technical advancements. In Singapore, the most established smart service is the Intelligent Transportation System (ITS); its development could be tracked back to ten years, also the system of e-government that has been developing from early 1980s. The Smart Nation Vision consist of a comprehensive continuum, which includes smart education, health, energy, buildings, security, transport and many more aspects. Smart services are both in the planning phase and also some have been launched as trails. Singapore is a unique and interesting example of a country being developed in its entirety with utilisation of extremely innovative smart schemes (Lee, et al., 2016).

Smart and efficient environmental initiatives are of utmost importance to Singapore, due to the nation's dense population and limited land area. Some of the lessons that may be learnt from Singapore is their cautious approach towards smart city implementations. For instance, the country makes decent use of trial projects before the implementation phase of smart services nationally. On the other hand, Singapore has a certain advantage in terms of pilot projects compared to other international cities, because of its wide-ranging ownership of public housing (Public Utilities Board, 2012). Approximately eighty percent of the country's population resides in public housing. Therefore, it is made easier for public entities to test smart trail services resembling in-house displays. In addition, Singapore is also a good point of reference for other future smart cities around the globe, concerning smart integration. In other words the integration of smart solutions from various scopes and services that overlap between the different fields of the urban space. Hence, Singapore established a common

platform for the maximum utilisation of effective data sharing, smart devices and to minimize costs.

The case study of Singapore offers a unique example of a national approach towards becoming a Smart Nation. At that time, there were no other cases where the country as a whole was being transformed under the careful direction, planning and funds of the central Government. Lee, et al. (2016) believes Singapore is unique in comparison to alternative smart city initiatives from across the world.

2.7.2 Amsterdam, Netherlands

The Amsterdam municipality decided in 2009 to establish Amsterdam as a Smart City (Mora & Bolici, 2017). Citizens of Amsterdam, private businesses and research institutions collaborated due to the attraction of a strong political will and a masterplan with exact timelines. Results have led to the largest number of original ideas that were incubated in comparison to global cities. Amsterdam has since then implemented more than sixty individual smart city projects. For example, the Smart Mobility Project, which promotes the mass use of cars that rely on electricity that are drawn from domestic solar panels and excess power from a household, could be sold back to the grid (Ehrhardt & Nilsson, 2012). Another smart city project is the Smart Grid, where a self-sufficient community of 40 000 households agreed to test a self-healing energy network. The grid has the highest concentration of solar panels in Amsterdam and is setup with smart meters. The reason for the remote access is that it results in zero outages and allows smarter maintenance programmes.

In addition to saving power, Amsterdam's municipality also installed Smart Dimming programmes, which are streetlights that are pre-programmed to dim when low activity is detected in the area at specific times (Mora & Bolici, 2017). Furthermore, carbon dioxide emissions are reduced through the Smart Parking project, where residents are allowed to pre-book parking spots and reduce the time spent and emissions produced to look for parking. The Smart Work Centres increases the city's liveability and environmental protection, the project consists of fully functional office spaces that are erected alongside the highway grid that specifically experiences major traffic congestion. Therefore citizens can decide to pull into the work centres and carry on with their work, instead of sitting in slow-moving traffic. Finally, it is encouraged that newly developed houses are setup to focus on sustainable energy, water and waste management, through promotion projects. Amsterdam is at the forefront when it comes to the concept of a smart city. The city of Amsterdam also

shares knowledge and experiences with the rest of the world, making it one of the best smart city programmes (Mora & Bolici, 2017).

2.7.3 Orlando, United Sates of America

Orlando is an international destination for sporting events, conventions and theme parks, where the smart city operation was approached through Orlando Operations Centre (OOC), an integrated facility that was established in 2001 after the hurricane natural disaster in 1977 (Lee, et al., 2016). The major feature of the integrated operation was risk management, which included CCTV cameras and shared fibre optic networks, and close cooperation between fire, police and transport departments. For the purpose of disaster, criminal and road incidences, including the OOC's emergency operation centre who takes lead during a special event or a large-scale natural disaster. Together with the OOC, Orlando's city hall has incorporated smart city functions, for example GPS garbage truck tracking, GIS water management and AVL technological bus management. Benefits that Orlando citizens have experienced, due to smart city initiatives include shortened response and decision-making time, enhanced quality of services, improved public communications and participation, reduced operation cost, and improved environmental impacts (Lee, et al., 2016).

The case study of Orlando is a good example of where a centre of various city operations integrate ICT systems relatively early in 2001, in advance of increased international attractiveness of smart city initiatives. The case is significant, due to the Orlando Operations Centre being established not by state or federal drive for smart city projects, but because of the need identified for rapid civic response on natural disasters and special events. Orlando is a good point of reference for any city requiring efficient disaster and emergency management, with regards to its hurricane-prone nature and large tourism industry. The Orlando case study indicates why smart city initiatives are necessary and not only for the purpose of becoming a world-class city, but to ensure protection to the city's environment and citizens (Lee, et al., 2016).

2.7.4 Addis Ababa, Ethiopia

Addis Ababa is the administrative capital of the African Union and therefore hosts large congregations of dignitaries (Lozano & Petros, 2018). Addis Ababa's city development is constrained by its transport network, which is unideal and similar to many small African countries due to the old roads that are unsuitable for expansion, therefore a smart city project had to be considered (Heisel & Woldeyessus, 2017). With urban migration and

economic growth the problem of traffic congestion increases, which subsequently increases pollution and reduces efforts towards environmental preservation. Rather than seeking a road-based solution, Addis Ababa decided on a smart city initiative and solution. As a result of implementing the rail-based solution, the dependency on individual automobiles have decreased, which in turn decreases the production of greenhouse gas emissions. In comparison to road travel, the smart city initiative is much more environmentally sustainable, which indicates the assurance of the smart solution. The Smart system moves large quantities of commuters, as opposed to road travel solutions that try to accommodate large numbers of automobiles. The system accommodates a large portion of the population and is much more sustainable for future years (Lozano & Petros, 2018).

This case study is of importance, as it indicates that the obvious solution is not always the best and we need to identify innovative and smart city solutions to current urban challenges, for the purpose of conserving and enhancing environmental sustainability. International platforms that support the efforts of cities, such as the mentioned above, to reduce greenhouse gas emission include the C40 Cities Climate Leadership Group and the World Association of Major Metropolises. Which is reinforced by the 2015 Paris climate agreement (UNFCCC, 2015).

2.8 City of Tshwane shift towards a Smart City

The City of Tshwane is the administrative centre of South Africa, certain sectors of the urban economy are thriving, and the City is adapting remarkably well to globalisation (SACN, 2016). Some features of a Smart City are present within the City of Tshwane, and such elements may thus be measured and evaluated to exploit opportunities, specifically regarding the contributions towards environmental quality (Singh & Kumar, 2017). Elements include the utilisation of alternative energy systems, a built environment that takes into account the City's environmental sensitivity, well-known initiatives for waste management and water conservation, and strong awareness regarding recycle and re-use opportunities (City of Tshwane, 2013). Consequently, the City of Tshwane plays a vital part in the Smart City Movement of South Africa. The City of Tshwane's shift towards a Smart City has gradually been gaining momentum and priority - it is thus necessary that the current smart level of the City of Tshwane is measured and the findings are evaluated, specifically to identify the contributions towards the City's environmental sustainability concerning this study (Li, et al., 2009).

The City of Tshwane has a number of components of a Smart City, which includes – being the governmental capital in South Africa and having every national department situated within it. The

City is situated within the Gauteng Global Region that is one of the most rapid developing economic regions in Africa and the City's population consist of approximately two million people. Furthermore, the City has the leading level of education fulfilment in South Africa (City of Tshwane, 2015). The City is a countrywide hub of learning and research. Due to the fact that the City contains four main tertiary institutions and seven out of the eight national Science Councils, namely the ARC (Agricultural Research Council), MRI (Medical Research Institute), CSIR (Council for Scientific and Industrial Research), HSRC (Human Science Research Council), NRF (National Research Foundation), SABS (South African Bureau of Standards) and the VRI (Veterinary Research Institute). In addition, the City also hosts Blue IQ's effective projects namely the Automotive Supplier Park, Eric Molobi Innovation Hub and The Innovation Hub. Another component of a Smart City is the City of Tshwane's existing and future plans of a fibre-optic network infrastructure for the purposes of rolling out broadband to government facilities, businesses and citizens (City of Tshwane, 2013).

Although the City of Tshwane includes a number of smart city elements, it is also essential to identify the developmental challenges that may limit these opportunities. Cities need to develop sustainable growth paths and priorities, where systems are implemented to monitor performance (SACN, 2016). South African cities, including the City of Tshwane, were built to be ineffective for the majority and to serve a smaller, selected minority. The cities were not planned or designed with a sustainable or inclusive future in mind (AFDB, OECD & UNDP, 2016). However, these cities have not been static after the Apartheid regime – the cities have gone through legitimately profound changes, and the changes have been driven by numerous forces, and not only governmental planning. As metropolitan government, challenges that also constrain the City of Tshwane includes that of being a facilitator, leader, regulator, initiator, and a strategic partner in supporting the spatial transformation and socio-economic objectives of its populace. In addition, the complexity of the City's inequality, poverty, social exclusion and employment challenges, additionally the global pressures of changing conditions, have demanded the need to re-evaluate the City of Tshwane's developmental framework.

In recent years, the City of Tshwane has begun to develop strategies to develop into a more ICT integrated city that includes the population, supports green economies and enhances environmental sustainability (City of Tshwane, 2015). The City has also established initiatives to expand its economic competitiveness, enhance integration, bridge the digital divide, develop social capital via online training, and advance agribusinesses. Hence, several attempts have been made by Tshwane to become a smarter city (Mirembe, 2017). To further develop as a Smart City and become globally competitive, the City needs to construct a platform for engaging with research organization, governmental departments, private sector and universities, in such a

way that is synergistic to encourage collaboration. In addition, joint intellectual expertise needs to be attained through combined city projects with strategic stakeholders intended to increase growth, public participation, development and equity.

Municipal planners of the City of Tshwane should individually identify how the concept of smart cities can take their municipalities towards a better future, whilst improving environmental sustainability (GDARD, 2014). Tshwane municipalities do not have to be heavily resourced to contribute toward a becoming a Smart City (SALGA, 2015). In the IN.KNOW.VATION Report (2015) compiled by South African Local Government Association (SALGA) it is stated that to become a Smart City, thought processes must be different and problems need to be addressed with innovative approaches. Elements of a Smart City can be applied today within local municipalities. Currently, South African metros are progressively adopting the New Urban Agenda of globalisation, urban development and national development. Whilst committing to the Sustainable Development Goals, especially Goal 11 on Sustainable Cities. Related policy interventions in the urban space by government include Integrated Urban Development Frameworks (IUDFs) and Spatial Development Frameworks (SDFs) as required by SPLUMA for the spheres of government. Furthermore, SPLUMA enhances spatial sustainability and environmental justice as key principles of land use management and spatial planning.

2.9 Smart City movement interrelated with Tshwane planning principles

A strong link exists between the Smart City Movement and the Sustainability Movement, with interrelated principles such as resilience, spatial justice, spatial efficiency and good governance, which all contribute towards environmental sustainability and better resource utilisation. Town planning schemes of the City of Tshwane further provide for these principles, which includes the Technical Report for the Gauteng Conservation Plan (Gauteng C-Plan v3.3), Tshwane Open Space Framework, National Development Plan, Spatial Planning and Land Use Management Act, 16 of 2013 (SPLUMA), Integrated Development Plan and the South African Cities Network. It is essential that performance indicators for evaluation frameworks are constructed according to the key principles set out in these schemes for improved development across various sectors.

The Spatial Planning and Land Use Management Act 2013, is an overarching framework for spatial policy, land use management and planning in South Africa, which includes informal and rural settlements. It is important to note that the ineffective application and implementation of spatial planning and land use management tools could lead to exclusion and unsustainability concerning the social, economic and environmental sectors. Legislation needs to be aligned with equity and sustainable development principals and emphasis should be drawn to lowering the

demand on natural resources through urban planning schemes, for the ultimate goal of increasing development sustainability.

2.10 Literature review findings

2.10.1 Research topic gaps

It was found that there are limited literature and studies that link the different concepts of the study within a South African context. South African literature studies are focused on the different concepts separately, namely “Smart Cities” and “Environmental Sustainability”. In addition, there are limited research projects that integrate these concepts to provide better guidelines and interventions to implement smart city interventions for the specific purpose of improving environmental sustainability within South African cities. Missing elements that I have considered could be illustrated through empirical work, due to the fact that there are existing theoretical debates in abundance in the smart city and environmental sustainability fields (Bennett, 2005). Furthermore with regards to the study at hand, there has been found that there are no attempts to evaluate the City of Tshwane’s smart city level according to the Smart City measure of European Cities and how this measured Smart City level of Tshwane contribute towards the city’s environmental sustainability. Currently in South Africa, there is a shortage of research on the subject matter. Even though The City of Tshwane includes smart city elements, the City could be developing more sustainably, largely due to the current development path that is resource-intensive, system inefficiencies that exist across some sectors and the shortage of adequate monitoring systems (City of Tshwane, 2013). Thus, it is vital that the Smart City level of Tshwane is measured and compared to international standards, to gain knowledge on the topic and to presumably contribute towards environmental health, international competiveness, and human wellbeing.

The above review of literature has also indicated some of the numerous approaches and methods that have been applied to evaluate and formulate guidelines for the implementation of smart cities. The various available approaches to evaluate smart cities and related issues, could lead to challenges when building a consensus on which measures and methods needs to be applied by cities to become smarter, in order to positively contribute to environmental sustainability. In addition to this, the existence of wide-ranging urban and environmental associated challenges within cityscapes have led to the formulation of numerous urban environmental and innovative city definitions or approaches, as mentioned above, therefore challenges have arisen specifically concerning adoption and acceptability. Some emphasize only the environmental aspects, others also include infrastructure, environmental and socio-economic elements, whilst some include resilience, policies, plans and ICT technologies

(Campbell, 1996). The study at hand combines the smart city concept, with the concept of environmental sustainability. Thus describing the natural world within a city and how urban initiatives can affect the natural conditions.

2.10.2 Emerging themes and trends

The literature that was appropriate in answering the research questions was mostly found in journals by looking at different peer reviewed articles and library books. Finalised exclusion and inclusion criteria was used for the systematic review of literature. Different themes have been discussed in the literature review to create a strong structure and study focus. The literature that was studied have been categorised into two different themes that are smart cities and environmental sustainability, which might initially be assumed to be two different themes (Christiaanse & Höger, 2006). The two different themes were then linked together into the general theme of the study that is the City of Tshwane's Smart City level evaluation, including the way in which this contributes to the city's environmental sustainability. The above literature study provides motive for integrating the two themes, also reference has been made to implications and solutions, international examples and future planning repercussions. The trend is indicated above that the term "Smart City" is an umbrella concept, which includes numerous subthemes, as mentioned above (Gudes et al. 2010; Cocchia 2014; Lara et al. 2016). The study at hand draws focus on the theme of Smart Cities specifically and in what way they contributes towards a city's environmental sustainability. Elgazzar and El-Gazzar (2017) states that the smart city concept is interconnected with that of a Green City, Sustainable City or Eco-city, indicating the strong linkage between the Smart City Movement and improving the environmental performance of an urban area.

A trend that also surfaced from different literature studies, with regards to the concept of smart cities and environmental sustainability performance, were when evaluated together and activities are interconnected it allows better overflow and enhancement of advantages for both sectors. Therefore, the skills and experience of environmental and urban planners need to add up to create a unique approach of problem solving and achieving objectives. This approach needs to include the identification of how technical information and facts relate to the bigger picture, recognising gaps in needed expertise and resources, establishing a linear process to achieve objectives and knowing how to make mid-course corrections and to package findings and recommendations for public consumption (Jones & Macris, 2000).

Cities are the key role-players in enabling sustainable change, therefore to meet environmental changes posed by historic shifts; they need to address current environmental issues that threaten future sustainability. As mentioned above this starts with the city itself, the smart city concept needs to be grounded to the city context, and subsequently environmental performance is enhanced and sustainability is stimulated. Due to this, the implementation of reliable tools to measure and evaluate performance on a city scale is of utmost important. The process of improved change needs to define the key concepts in the correct context, for example “Smart City”, “Environmental Performance”, “Sustainability”, or “Key Performance Indicators”. For the purpose of this study, the main aspect of the smart city concept is its incorporation of environmental sustainability. Thus, through the utilisation of advanced technology, cities could be developed and planned to be more equipped to address today’s urban challenges, which have negative effects on the natural environment. Furthermore, the process also needs to include the evaluation of performance indicators and the design of relevant metrics to achieve research objectives.

From the above review of literature, approaches are indicated by what means Smart Cities could significantly influence environmental sustainability of a city and this could be briefly summarized as the following;

- Reduce carbon emissions
- Support energy efficiency
- Improve urban waste management
- Real-time management and monitoring of energy and environment
- Improved citizen engagement
- Smart mobility projects
- Sustainable energy and water management

Hence, the ultimate recurring theme of the literature review is the way in which a city’s environmental sustainability can be enhanced by smart city initiatives to improve the quality of life of residents through the protection of natural resources. Natural resources are used more sustainably when the urban environment adopts smart city elements (Cafuta, 2015). This continuum therefore supports the notion of maximising the utilisation of natural resources by enabling the relationship between urban planning and environmental management disciplines.

2.11 Synthesis

The purpose of the literature review is to identify international examples, create a research background, and indicate how the study would contribute to the field. An in-depth literature review is conducted for the purpose of gaining knowledge of the research topic, and also to then formulate an adequate synthesis of the study. Different themes have been discussed in the literature review to create a strong structure and study focus. It is essential to comprehend the current situation of the City of Tshwane, to formulate and appropriately adopt innovative smart city strategies for the purpose of improving environmental sustainability. By providing smart city initiatives from a range of literature studies, the cityscape of Tshwane can thus be reconsidered to enhance environmental sustainability for the realisation of economic and social objectives (Haughton, 1997). The recurring theme of the literature review is the way in which a city's environmental sustainability can be enhanced by means of smart city initiatives, for the purpose of enhancing the quality of life of residents by protecting natural resources. Natural resources are used more sustainably when the urban environment adopts smart city elements (Cafuta, 2015). The literature review conducted on Smart urban environments indicated various notions of what is generally termed a "Smart City". When one looks at the concept, regarding urban development and growth, from a traditional regional and neoclassical theoretical point of view smart city programmes have six dimensions or axes. Caragliu et al. (2009) summarises these smart city dimensions as – smart mobility, economy, people, governance, living and lastly the smart environment. Furthermore, social and environmental sustainability are confirmed by Cozens (2008), Greenburg (2004) and Toppeta (2010) to be the clear vision of smart cities, as a response to the increasing need for more efficient, liveable, and sustainable urban development models.

Due to the above, the view of sustainability will be mostly focused on environmental performance and some social aspects, to also include the theory of environmental justice. Therefore, it is the opinion of the author that the application of the *EUROCITIES CITYkeys* Key Performance Indicators on city-level is the most applicable framework to adequately measure the City of Tshwane's smart city performance. The *EUROCITIES CITYkeys*' Key Performance Indicators include the following themes; prosperity, planet, people, propagation and government, of which the research report at hand focusses on the people and planet theme indicators to be measured. The people (social sustainability) and planet (environmental sustainability) themes are commonly applied in the formulation of an indicator system for the purpose regional and national urban growth (Bosch, et al., 2017).

Although the City of Tshwane contains various smart city elements it is vital to further identify the developmental challenges that may limit these opportunities. Cities need to develop sustainable growth paths, where systems are implemented to monitor performances (SACN, 2016). South African cities, including the City of Tshwane, were built to be ineffective for the majority and to serve a smaller, selected minority. The cities were not planned or designed with a sustainable or inclusive future in mind (AFDB, OECD & UNDP, 2016). A renewed interest to provide better and innovative city services need to be realised, after decades of limited change in the Tshwane Metropolitan region.

To conclude, smart technological advancements establish new opportunities for various smart city regeneration and development programmes formulated to address social and environmental challenges located within cities. It is clear that smart city programmes have received much public promotion; however there is lack of discussion concerning evaluating smart programmes and measuring their outcomes on a city and project level. Different components and elements of the literature study have been interlinked to create a connected whole. Thereafter the different components are brought together to obtain a better understanding of the research topic. In addition, a clear result is obtained by considering the smart city concept and environmental sustainability concept separately, and then combining the two components together, intended for environmental urban planning of the City of Tshwane. Finally it is indicated, that a review of existing and obtainable research and literature regarding the relationship among key performance indicators, smart city levels, and the link between environmental sustainability, proposes that the research questions and overall research topic is still indecisive, thus further empirical research about the topic is necessary.

3. CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

3.1 Research design and approach

"A research method is a strategy of enquiry which moves from the underlying philosophical assumption to the research design and data collection" (Myers & Avison, 2002, p. 7)

A comparative research approach was followed regarding the Smart City level of the urban spaces of the City of Tshwane and the chosen European city standard was applied, due to the fact that the approach provides better insights concerning a performance based analysis. Once the Smart City levels were measured according to the Key Performance Indicators of the *EUROCITIES CITYkeys* framework, a basis of progress and smart city initiatives are provided. Terms such as 'metrics' and 'indicators' are used interchangeably for the purpose of this study. City-level indicators according to the *EUROCITIES CITYkeys* may be applied to compare cities with one another, and these comparisons have been carefully considered (Bosch, et al., 2017).

The following smart city definition was specifically applied when the study was conducted – *"a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green" referring to urban infrastructure for environment protection and reduction of CO_2 emission, "interconnected" related to revolution of broadband economy, "intelligent" declaring the capacity to produce added value information from the processing of city's real-time data from sensors and activators. Whereas the terms "innovating", "knowledge" cities interchangeably refer to the city's ability to raise innovation based on knowledgeable and creative human capital"* (Zygiaris, 2013, p. 217).

After the smart city indicators have been applied and measured, the study continues to identify how this contributes towards the environmental performance of the City of Tshwane. The environmental sustainability contributions were assessed according to standards acquired from various peer reviewed literature studies.

The use of different research methods is referred to as triangulation, and is utilised to validate findings. The technique of triangulation facilitates the validation of data, via cross verification from different sources (Myers & Avison, 2002). The approach includes identifying how technical information and facts relate to the bigger picture, recognising gaps in needed expertise and resources, establishing a linear process to achieve objectives and knowing how to make mid-course corrections and to package findings and recommendations for public consumption.

3.2 Rationale for study

3.2.1 Study area rational

The study was applied to the City of Tshwane, in an endeavour to explore the environmental sustainability of the City and how to enhance it, while considering general limitations and the scope of the dissertation. Observably, the City of Tshwane is not currently performing at its fullest environmental potential (Lucas, 2011). The study area thus provides the opportunity to evaluate and compare performances, and propose interventions (Pacione, 1990).

The rationale for the study area takes into account the fact that the City of Tshwane is the administrative capital of the country, certain sectors of the city economy are thriving, and the City is adapting remarkably well to globalisation (SACN, 2016). The City of Tshwane is situated in one of the smallest provinces of South Africa's nine provinces and has one of the largest economies in the country (City of Tshwane, 2013). The Department of International Relations and Cooperation states that the City of Tshwane is the 'intellectual capital' of South Africa, due to numerous research and development, and tertiary education institutions (Department of International Relations & Cooperation, Foreign Representation, 2013). Thus features of a Smart City are present within the City of Tshwane, and such elements can thus be measured and evaluated to exploit opportunities, specifically regarding the contributions towards environmental quality (Singh & Kumar, 2017). In addition to this, the complexity of the City's inequality, poverty, social exclusion and employment challenges, in addition to the global pressures of changing conditions, have demanded the need to re-evaluate the City of Tshwane's developmental framework.

It was found that there are no attempts to evaluate the City of Tshwane's Smart City level according to the smart city measure of European Cities and how this measured Smart City level of Tshwane contribute towards the city's environmental sustainability. Currently in South Africa, there is a lack of research on this topic and therefore necessary to further explore that of the City of Tshwane.

3.2.2 Research type rational

Two different types of research approaches have been applied to answer the separate research questions. The use of two different research methods is referred to as triangulation and is utilised to check findings of the same and one subject.

The research questions are structured as the following;

1. How does the City of Tshwane compare to the Smart City measure of European Cities?

2. Does the measured Smart City level of Tshwane contribute towards the city's environmental sustainability, and if so how?

Before explaining the rationale for integrating the two specific approaches, one must first generally understand them separately. The objective of applying the first approach of *EUROCITIES CITYkeys*' Key Performance Indicators (KPIs) as a Smart City level measurement aims to provide a holistic, performance measurement framework that is validated, for the purpose of comparing and monitoring the development of a smart city. *CITYkeys* followed a bottom-up process for the development and validation of the standardised performance indicators and data collection processes. The process was based on the necessities of citizens and their cities. The KPIs are classified based on themes, in order to map them efficiently. The research report at hand focusses on the "People" and "Planet" theme indicators for a city level evaluation. The People (social sustainability) and Planet (environmental sustainability) themes are commonly applied in the formulation of an indicator system for the purpose of regional and national urban growth (Bosch, et al., 2017). The final set of indicators that were applied to the City of Tshwane, to measure and assess the Smart City level and answer the research question, have been selected according to reliability, measurability, availability, and relevance. The indicators are grouped under general themes, by using the *CITYkeys* report as a guideline. The top themes that have to be measured within a city, with a smart city performance measurement system on city level according to a city's general needs, are "Citizens participation", "Resource management", "Digital infrastructure and services", "Transportation", "GHG emissions" and "Energy". The *CITYkeys* found that various cities consider the smart city concept as extremely significant, however the cities have no appropriate measurement or evaluation system in place.

The second approach of assessing environmental sustainability contributions, according to standards and secondary data acquired from various peer reviewed literature studies, is generally applicable for qualitative research. The approach aims to analyse scientific studies that are significant to the findings of the first research approach. Therefore, the research approach is focused on both smart city concepts and environmental sustainability to better understand how the concepts are related and contribute towards one another. The approach was applied to identify information about frameworks, tools and researchers, focusing on the two specific research concepts. The qualitative methodology, through a systematic literature review, examined the terms 'smart city' and 'environmental sustainability', directed at the contributions smart city initiatives make to environmental sustainability within an urban setting. The adjacent literature review approach expands

what was found during the key performance indicator approach of the study area. The evaluated Smart City level provides the overall picture of the study area, where as for the literature review approach zooms into the picture, for a more in-depth look at the relationship between smart city initiatives and environmental sustainability. It should be acknowledged that once processing qualitative data, the element of subjectivity is unavoidable, though the researcher's views that are enriched through the experience of the practitioner, therefore the approach is not as neutral as one might need it to be (Iacono, et al., 2009).

3.3 Methodology

Specific research approaches have been applied to answer the separate research questions, which are the use of the *EUROCITIES CITYkeys*' Key Performance Indicators as Smart City level measurement and the contributions towards environmental sustainability on a city level that is (assessed through an extensive literature review). The Key Performance Indicators are quantifiable measurements for a cityscape and the literature review approach includes the study of peer reviewed articles and municipal documents, combined with a deductive approach (Darke, et al., 1998).

The overall objective is to plan and recommend the most appropriate city environment that can foster the dynamic interactions necessary to implement sustainable and adaptable smart city projects for the purpose of enhancing the quality of the natural environment. The smart city evaluation framework should be developed in accord with the needs of the study city and the framework needs to be developed according to expert and tested guidelines. The framework should be adaptable and flexible to reflect different city circumstances and complex city challenges, including the appropriate amount of KPIs covering all the meaningful city indicators rather than having a restricted focus, and could be improved in response to new city mechanisms.

The research approaches followed for the separate questions are described on the following pages;

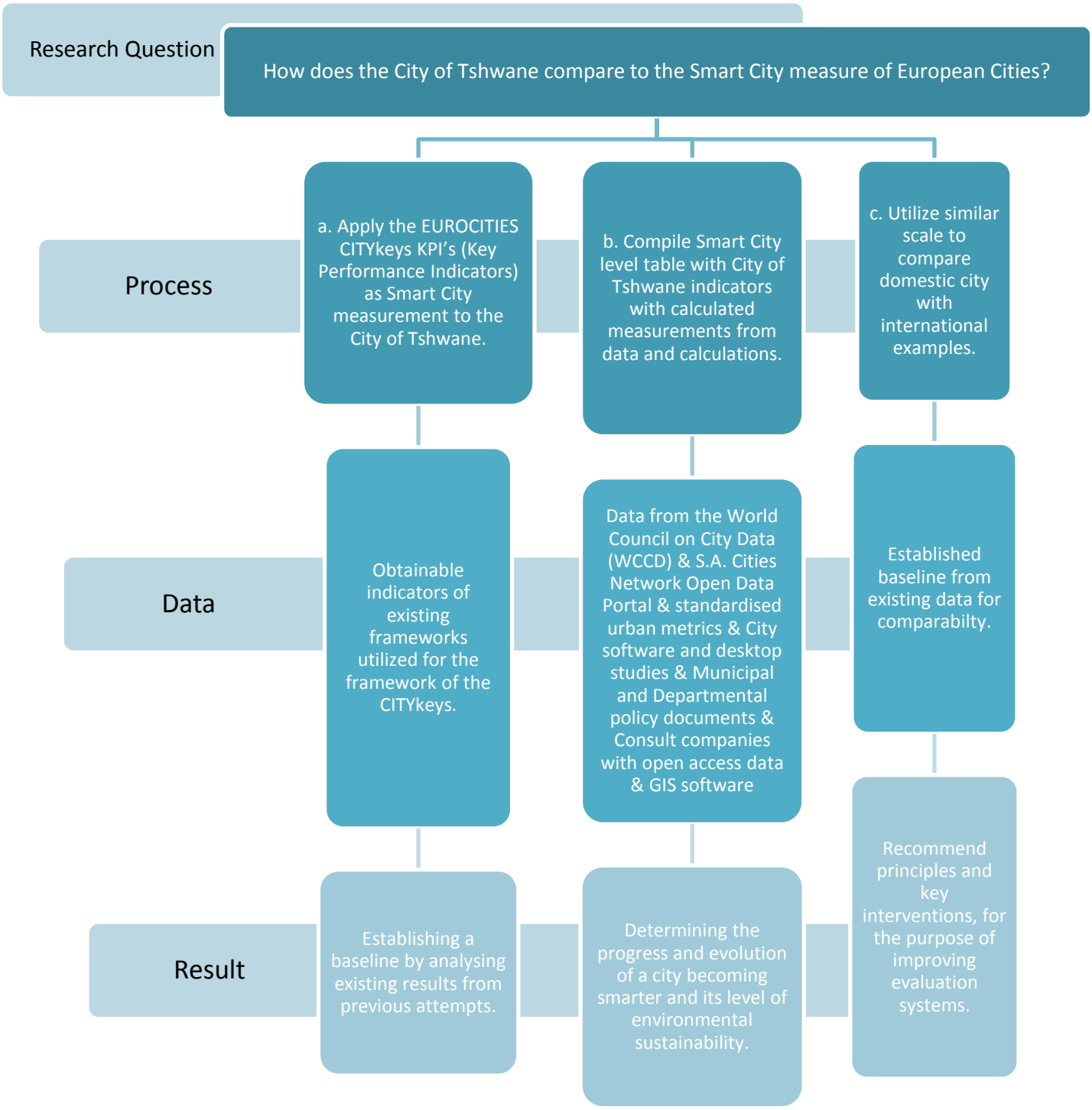

Figure 1: Research question 1. Process

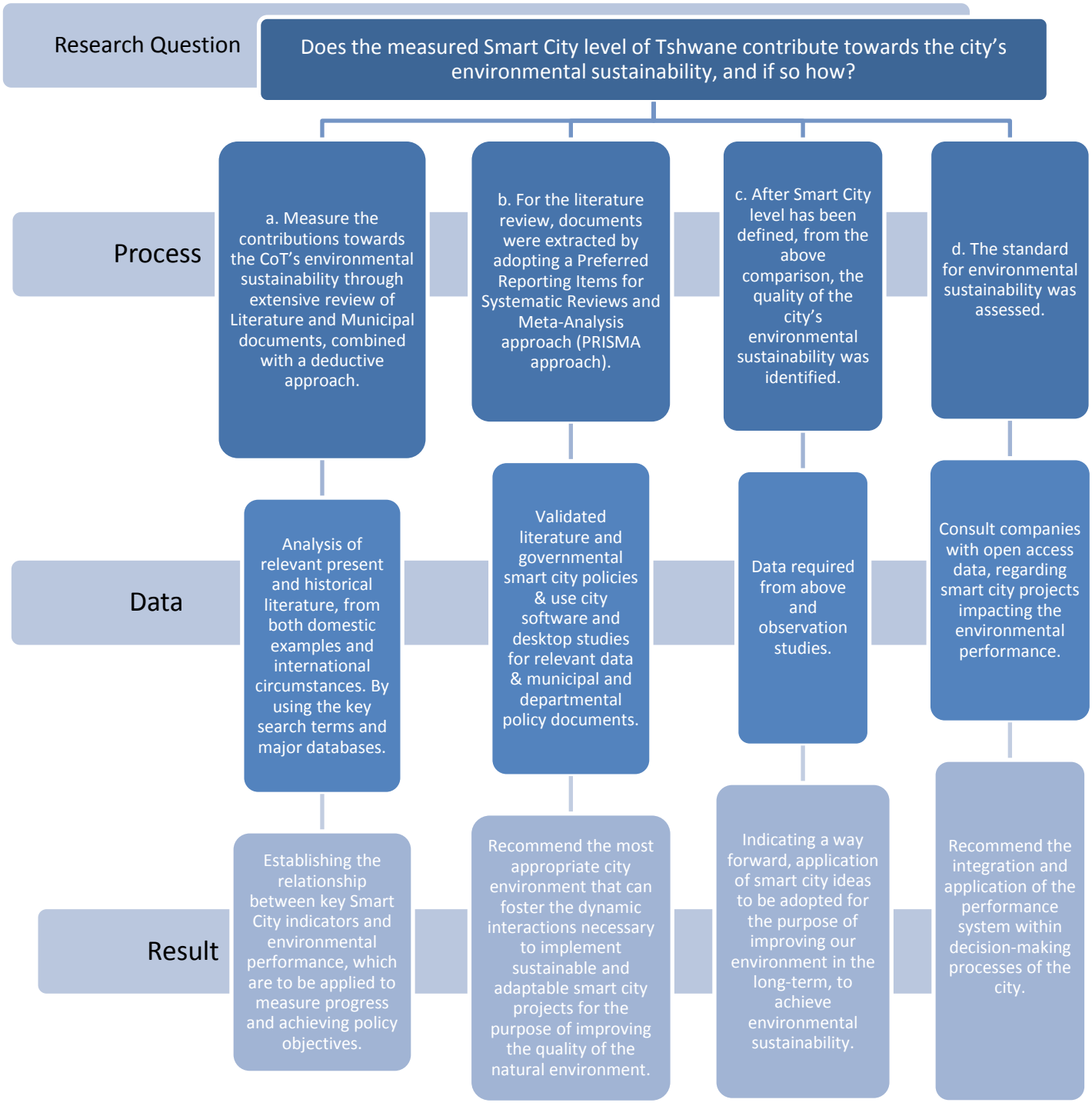

Figure 2: Research question 2. Process

3.4 Key performance indicator research approach

3.4.1 Overview and objectives

The Bank for Reconstruction and Development of Europe (EBRD) states that a city, which is characterised predominantly by its environmental quality, maximises social benefits. This was applied for the selection and prioritisation of the Key Performance Indicators (KPIs) from the *EUROCITIES CITYkeys* standard. *CITYkeys* developed the large set of indicators, according to an inventory done on the needs of citizens and cities, their functioning definitions and the shape of their assessment framework. The *EUROCITIES CITYkeys*' KPIs include the following themes; prosperity, planet, people, propagation and government, of which the research report at hand focusses on the people and planet theme indicators, for the purpose of answering the research questions.

Key performance indicators originated in business administration and are always linked to objectives, goals or targets. Performance indicators provide tools of measurement and evaluation (DEFRA, 2006). With regards to the *CITYkeys* KPIs, the measures are significant for understanding smart city implementation impacts, and the prevention of complex and lengthy reports on less relevant aspects. Furthermore, the *CITYkeys* framework is enabled to process future developments on the similar adequate level as current developments (Bosch, et al., 2017). The *CITYkeys* report is throughout divided into two sections, which are the Smart City project measures and the Smart City measures on a city scale. For the purpose of this study, we will only be applying the Smart City Key Performance Indicators on a city scale, which is most relevant to answer the research question.

From the smart city definitions, success is only achieved once transition has taken place throughout the complete ecological footprint of a cityscape, whilst economic success and societal improvements are promoted, and environmental resilience and protection are achieved. After all, the sustainability concept has come to be generally acknowledged in the formulation of indicator frameworks for regional and national city growth. It should also be taken into account that the concept of sustainability is divided into the triple bottom line of environmental, economic and social sustainability (SCOPE, 2007). The standardised *CITYkeys* assessment framework provides support for Smart Cities in enhancing measures of progress and strategic planning. Therefore, selected indicators are mainly performance orientated (Hiremath *et al.,* 2013).

Boundaries of the research approach include the application of only relevant indicators that contribute to answering the research question. Therefore, the people (social sustainability) and planet (environmental sustainability) themes were mostly applied in the formulation of the indicator system for this study, and the study will not cover indicators that are irrelevant from themes such prosperity, propagation, and government from the *CITYkeys* report. It is by no means a straightforward task to measure the extent to which a city is getting smarter. Therefore, limitations to the study approach also includes, the issues of measuring direct links between smart city implementations and activities, for example KPIs measure the performance in a specific urban area, but they do not measure the implementation effects on city outputs. However, concerning this study, the limitation at hand will be addressed by conducting a literature review, specifically in accordance with the contributions of smart city outcomes on environmental sustainability.

The combination of the two different approaches support one another to promote the accuracy of findings. As a vital part of the study, the input of generalised data has been utilised to assess and evaluate the cityscapes and data sources, and situations will be specifically referenced, with regards to study findings, to validate comparisons. Smart city elements that contribute towards environmental sustainability of a city could include pollution reduction methods and technologies, increased attractiveness and quality of the city's natural environment, sustainable resource management and adequate protection of the environment (Giffinger, et al., 2007). Indicators have been calculated numerically or a carried weight has been provided to compare mutually significant indicators.

In conclusion, the research objectives of the key performance indicator approach includes - the development and validation of a transparent performance evaluation framework for the City of Tshwane, formulating recommendations for the integration and application of the performance system within decision-making processes of the city and also providing a platform for the engagement of stakeholders in identifying and exploiting opportunities for the City. Ultimately, the objective when applying the *CITYkeys* indicator framework is to promote rapid widespread adoption and implementation of smart city services and solutions in order to achieve sustainable environmental goals within the urban space of the City of Tshwane.

3.4.2 Sources and collection of data

Research Questions	Methodology	Data Required
1. How does the City of Tshwane compare to the Smart City measure of European Cities?	a. The use of the *EUROCITIES CITYkeys* KPI's (Key Performance Indicators) as smart city measurement. - A KPI is a quantifiable measure to evaluate performance on smart city objectives. The measurements are metrics, based on a standardised method. - Establishing a baseline by analysing existing results from previous attempts. - Main indicator themes are social and environmental. - The units of the indicators needs to be comparable, thus indicators are defined as numerical measurements, such as '% of change' or 'number of indicator per 100,000 population'. - Obtainable indicators of existing frameworks were utilised for the framework of the *CITYkeys*. b. Compile Smart City level table with City of Tshwane indicators with calculated measurements from attained data and calculations. c. Utilise similar scale to compare domestic city with international examples.	- Data from the World Council on City Data (WCCD), S.A. Cities Network Open Data Portal and further comprehensive open city data platforms were utilised to obtain standardised urban metrics. - Relevant datasets were selected which show a range of indicators for smart city performance. - Use city software and desktop studies for relevant data. - Municipal and Departmental policy documents. - Consult companies with open access data. - The use of GIS software. - Data were also collected from activities that have already taken place within the cityscape.

Table 1: Research question 1. Data Collection

3.4.3 Selected Smart City Key Performance Indicators

The definitions of the selected city-level indicators are indicated below, also the indicator units. From the identified smart city definition, appropriate indicators have been specifically selected for the function of Key Performance Indicators (Bosch, et al., 2017). The selected indicators focus on determining the progress and evolution of a city becoming smarter and the level of environmental sustainability. The people (social sustainability) and planet (environmental sustainability) themes were applied in the formulation of the indicator system for the purpose regional and national urban growth (Bosch, et al., 2017).

Indicators are selected to link social equity, environmental sustainability and environmental justice. Through the application of the *EUROCITIES CITYkeys*' KPIs, the development and validation of a transparent performance evaluation framework for the City of Tshwane could be established. The evaluation further identifies sectors for which it is necessary to be integrated in order to construct a relevant common metric, to achieve the overall objective.

Social Indicators		
Title of Indicator	**Indicator Definition**	**Indicator Unit**
Access to services		
Access to public transport	Number of bus stops, provided by the City. Coverage of the city area.	%
Length of bike route network	Bicycle paths and lanes in comparison to international standard, not including motorways.	% in km
Access to free public Wi-Fi	Wi-Fi coverage of public spaces.	% of km^2
Safety and wellbeing		
Crime rate	Number of crimes per 100,000 population.	# /100,000

Fatal traffic accidents	Total of transportation fatalities per 100,000 population.	# /100,000
Access to basic healthcare	Portion of population within city with basic health care services, accessible within 5km.	% of people
Education		
Environmental education	The percentage of schools with educational environmental programmes.	% of schools
Digital literacy and ICT	Percentage of reached target group.	% of people
Quality of housing and built environment		
Green public space	Green space per person.	m^2/ person
Environmental Indicators		
Title of Indicator	**Indicator Definition**	**Indicator Unit**
Environmental performance	Environment sustainability parameters, according to the WHO minimum standard.	2011 Africa Green City Index
Energy and Mitigation		
Energy consumption	Energy consumption that is final for all forms and uses of energy.	MWh/cap
Renewable energy generated by the city	As a portion of the total energy consumption within the city, the percentage of total energy derived from renewable resources.	% of MWh
Emissions of CO_2	Tonnes of CO_2 per capita per year.	t. CO_2/cap/yr
Total electric vehicle charging stations	The number of electric vehicle charging stations within the study city.	# electric vehicle charging stations

Materials, land and water		
Domestically consumed material	The total quantity of material consumed, directly within the study city per capita.	t/cap/year
Water consumption	Total amount of water consumed per capita per day.	litres/cap/year
Water losses	Water loss percentage, in relation to the total water consumption.	%
Population density	Total people per km^2.	# / km^2
Food production locally	Within a radius of 100km, the part of food produced.	% of tonnes
Brownfield use	Portion of brownfield area, which has been redeveloped in the past year, as a percentage of city area.	% of km^2
Pollution and Waste		
Nitrogen oxide emissions (NOx) data availability	Average percentage of data availability from five monitoring stations.	%
Air quality index	Annual air pollutants concentration, which are relevant.	Index
Municipal solid waste	The annual total municipal solid waste produced per capita.	t/cap/yr
Recycling rate	Percentage of study area's recycled solid waste.	% of tonnes
Ecosystem		
Share of water and green spaces	Share of water and green surface area, by means of percentage of overall land area.	% in km^2

Threatened species	Number of priority threatened species in the Bioregion.	# of species
Green economies		
Certified companies	Share of companies located in the study city with ISO 14001 certification.	% of companies
Green jobs	The amount of jobs associated with environmental activities and services, which significantly contributes towards restoring or preserving the performance of the city's natural environmental.	% of jobs
Amount of Green Public Procurement	Percentage of yearly procurement, using the share of environmental criteria in relation to the city administration's total annual procurement.	% in R
Innovation		
Innovation hubs	Number of innovation hubs within the study city (public or private)	# of hubs
Accessibility of open datasets	To which extent the open city data is accessible and user-friendly.	# of open datasets
Research intensity	Research and development spending as a percentage of city's gross domestic product.	% in Rand

Table 2: Selected Key Performance Indicators

3.5 Literature review approach

3.5.1 Overview and importance of approach

The environmental sustainability contributions of smart city initiatives are assessed according to standards acquired from various peer reviewed literature studies. The overall objective is to plan and recommend the most appropriate city environment that can foster the dynamic interactions necessary to implement sustainable and adaptable smart city

projects for the purpose of enhancing the quality and sustainability of the natural environment.

This section of the research project, intends to evaluate scientific readings that focus on both smart city concepts and environmental sustainability to better understand the relationship between the two. Dizdaroglu and Yigitcanlar (2014) stated that a sustainable urban development aims to support environmental consciousness, when interacting with natural resources within smart cities. The adjacent literature review approach expands what was found during the KPI approach of the study area. The section delivers a systematic literature review, where the literature was carefully chosen from different databases. Key search terms that were used included – 'smart city' and 'environmental sustainability'. The section strives to answer the following research question: Does the measured Smart City level of Tshwane contribute towards the city's environmental sustainability, and if so how?

The search strategy was designed for the systematic review of literature, in order to collect papers that represent the 'smart city' concept related to 'environmental sustainability' using Google Scholar. After which the selected subset was stored in an ad-doc database for the purpose of synthesis and organisation. The literature review subset was organised by extracting qualitative and quantitative data with reference to smart cities and their contribution towards environmental sustainability. Documents were extracted for the systematic literature review, by adopting a PRISMA method. A PRISMA method is the Preferred Reporting Items for Systematic Reviews and Meta-Analysis approach. The method is an evidence-based minimum that aims to assist researchers to report a wide range of meta-analysis and systematic reviews.

The importance of the literature review approach includes – the establishment of a relationship between key smart city indicators and its environmental performance, which could be applied to measure progress and achieving policy objectives. Indicating a way forward, application of smart city ideas to be adopted for the objective of enhancing the quality of the environment in the long-run. Finally, the findings of the literature review study also aims to provide invaluable insights for academics researching the subject, and public authorities considering to apply those into practice in their cities, for the purpose of enhancing sustainability of the natural environment.

3.5.2 Literature review process

A literature review is the foundation of scientific writing (Trindade, et al., 2017). The researcher identifies the renowned authors who have been writing on the subject and becomes familiar with the text, during the review of literature. The systematic analysis approach that was adopted for the study at hand searched for articles in different digital databases, such as Scopus, Emerald Insight, Science Direct, ACM Digital Library and Springer. The search keywords used were ‘smart city’ and ‘environmental sustainability’, in case studies similar to the City of Tshwane’s context or of which the City could gain and apply knowledge learnt from other smart city initiatives. The search was limited to the two specific terms, to better answer the research question, without adding to the confusion concerning the branding of the two different concepts.

The search string was developed according to fixed steps that were; firstly to identify the key search terms according to specific definitions stated above relating to environmental sustainability within a Smart City, secondly to narrow down the set of search terms to specifically answer the second research question. Then to search for the terms in titles, abstracts and lists of key words within literature studies. Key words and titles were evaluated to select documents that best dealt with the two terms ‘smart city’ and ‘environmental sustainability’. After which abstracts were read to identify the documents necessary to be read in full. After reading the articles, it is was considered which of them provided the most appropriate information concerning models, tools and frameworks that have been adopted in smart cities, which are in line with environmental sustainability goals. Ten documents were carefully chosen for the final analysis.

3.5.3 Sources and collection of data

Research Question	Methodology	Data Required
2. Does the measured Smart City level of Tshwane contribute towards the	a. Measuring the contributions towards the CoT’s environmental sustainability through an extensive review of literature and municipal documents, combined with a deductive approach. - Application of the search keywords that are ‘smart city’ and	- Articles from major digital databases, such as Scopus, Science Direct, ACM Digital Library and Springer. - Search for the terms in titles, abstracts and lists of key words within literature

city's environmental sustainability, and if so how?	'environmental sustainability'. - Analysing relevant present and historical literature, from both domestic examples and international circumstances. - For the literature review, articles were extracted by adopting a Preferred Reporting Items for Systematic Reviews and Meta-Analysis approach (PRISMA approach). Its objective is to aid the researcher with reports on wide range meta-analysis and systematic reviews. Also the approach is evidence-based. b. After Smart City level has been defined, from the above comparison, the quality of the city's environmental performance is evaluated. c. The standard for environmental sustainability was assessed and applied to the different cities through peer reviewed literature studies.	studies. - Validated literature and governmental smart city policies. - Use city software and desktop studies for relevant data. - Municipal and Departmental policy documents. - Consult companies with open access data, regarding smart city projects impacting the environmental performance.

Table 3: Research Question 2. Data Collection

4. CHAPTER FOUR: KEY PERFORMANCE INDICATOR RESULTS

4.1 City of Tshwane results

4.1.1 Test Scope

In the case of City of Tshwane the main interest, concerning this study, is in the city level evaluations. The tool that was applied, as mentioned earlier, is the *EUROCITIES CITYkeys*' Key Performance Indicators framework. The tool and its assessments were applied in such a way be able to target different management levels (operational and strategic) and, more specifically, operative level managers and local authorities. Furthermore, within the city targeted users of the evaluation tool also includes – research and area development departments, city managers, civil servants, experts working on projects or project development, relevant to the topic, and finally policy-makers and city level project managers. Thus, the tool is interrelated to the discussion of city strategies.

The selected themes that were addresses are linked to different city offices and it was expected that the main target groups are – offices of urban planning, energy, sustainable development, and environmental. Hence, the assessment focused on public services, materials and land use provided by local authorities. On a city-level, it was expected that the project at hand provides information to guide policy decision-making and to indicate opportunities and gaps in areas associated with a Smart City.

4.1.2 City of Tshwane case study description

City	City of Tshwane
General description	South Africa's administrative centre is the City of Tshwane, certain sectors of the urban economy are thriving, and the City is adapting relatively well to globalisation (SACN, 2016). Some features of a Smart City are present within the City of Tshwane, and such elements should thus be measured and evaluated to exploit opportunities, specifically regarding the contributions towards environmental sustainability within the urban context (Singh & Kumar, 2017).
Definition of the boundaries of the assessment	City level - Selected indicator themes are Planet and People, of which

(the scope of the assessment)	specific indicators were selected to better answer the research question. The city scale assessment was carried out as comprehensively as possible.
Aims of applying *EUROCITIES CITYkeys*' Key Performance Indicators to city	- Exploiting the results of the study for the purpose of city strategy planning. - Enhancing the development of the City's ecosystems and knowledge management systems. - Increasing availability and systems of data collection for public use. - Further, to develop and improve the KPI measurement applicable to the City, for mainly innovative urban development and environmental sustainability.
Data	The availability of data varied according to the KPIs, some of the quantitative KPIs were effortlessly accessible, and some were not available. Also concerning the study, city data for some of the KPIs are non-existent. It should be noted that there are various reasons for data not being available, within the case city. 32 KPIs were calculated.

Table 4: Assessed city description

4.1.3 City of Tshwane *CITYkeys* Key Performance Indicator results

Social Indicators				
Title of Indicator	**Indicator Definition**	**Indicator Result**	**Timeframe**	**Data Resource**
Access to services				
Access to public transport	Number of bus stops, within the city area.	23.13%	2020	City of Tshwane and A Re Yeng

Length of bike route network	The length of bicycle paths and lanes in comparison to international standard.	3.6%	2013	Tshwane Comprehensive Integrated Transport Plan (2014)
Access to free public Wi-Fi	Wi-Fi coverage of public spaces.	88% of km^2	2015	State of Cities Report: Dashboard Indicators (2016)
Safety and wellbeing				
Crime rate	Number of crimes per 100,000 population.	4983.85	2015	Development Information & GIS Department (2016)
Fatal traffic accidents	Total of transportation fatalities per 100,000 population.	10.1	2015	Comprehensive Integrated Transport Plan (2015)
Access to basic healthcare	Portion of population with basic health care services access within 5km.	86%	2013	Tshwane Vision 2055 (2013)
Education				
Environmental education	The percentage of schools with educational programmes relating to the environment.	5.6%	2005 - 2016	WESSA (2016), Tshwane Environmental Education and Awareness Strategy (2005)
Digital literacy and ICT	Percentage of reached target group.	53.7% *	2018	Internet World Statistics (2019)

Quality of housing and built environment				
Green public space	Green space per person.	$32.4 m^2$/ person	2019	CalcMaps and Tshwane SDF (Draft 2019)
Environmental Indicators				
Title of Indicator	**Indicator Definition**	**Indicator Result**	**Timeframe**	**Data Resource**
Environmental performance	Environment sustainability parameters, according to the WHO minimum standard.	Average	2011	African Green City Index (2011)
Energy and Mitigation				
Energy consumption	Energy consumption that is final for all forms and uses of energy.	8.81 MWh/cap	2012	Sustainable Energy Africa (2015)
Renewable energy generated by the city	As a portion of the total energy consumption of the city. The percentage of total energy derived from renewable resources.	0.11% of MWh	2012	NERSA (2014) and South African Cities Network (2014)
Emissions of CO_2	Tonnes of CO_2 per capita per year.	5.7 t.CO_2/cap/yr	2012	Sustainable Energy Africa (2015)
Total electric vehicle charging stations	The number of electric vehicle charging stations within the study city.	32 charging stations	2017	Nalini Sooknanan Pillay (2018)
Materials, land and water				

Domestically consumed material	The total quantity of directly consumed material within the study city per capita.	25-40 t/cap/year	2017	Africa Sustainable Development Report (2018)
Water consumption	Total amount of water consumed per capita per day.	322 litres/cap/year	2017	African Green City Index (2011)
Water losses	Water loss percentage, in relation to the total water consumption.	27.5%	2017	City of Tshwane Water Services Development Plan (2017)
Population density	Total people per km^2.	404 / km^2	2019	City of Tshwane (2019)
Food production locally	Within a radius of 100km, the share of food consumption produced.	25%	2013	South African Cities Network: Urban Food Security Report (2015)
Brownfield use	Share of brownfield area, as a percentage of total city area.	Data unavailable	2019/20	City of Tshwane, Urban Planning Department, city officials, BEPP, SACN, Tshwane SDF (Draft 2019), ResearchGate, Cities100, SDF (2018), IDP (2019), and Tshwane Compaction and Densification Strategy
Pollution and Waste				

Nitrogen oxide emission (NOx) data availability	Average percentage of data availability from five monitoring stations.	33.74%	2010	Department of Environmental Affairs (2010)
Air quality index	Annual air pollutants concentration, which are relevant.	>1 (More than one target's values of pollutants are not met)	2010	Department of Environmental Affairs (2010)
Municipal solid waste	The annual total municipal solid waste produced per capita.	0.78 t/cap/yr	2019	SACN Programme: Waste Management (2014)
Recycling rate	Percentage of study area's recycled solid waste.	25%	2019	SACN Programme: Waste Management (2014)
Ecosystem				
Share of water and green spaces	Portion of water and green surface area, by means of percentage of total land area.	24%	2019	Department of Environmental Affairs - Protected Areas Register Esri Map Tool
Threatened species	Number of priority threatened species in the Bioregion.	53	2016	Bioregional Plan for the City of Tshwane (Holness & Skowno, 2016)
Green economies				
Certified companies	Share of companies located in the study city with ISO 14001 certification.	53.3% *	2018	ISO Survey of certifications (Open Text SA, 2019)

Green jobs	The amount of jobs associated with environmental service activities, which contribute significantly to restoring or preserving the quality of the city's natural environmental.	0.21% of total number of jobs	2011-2012	Green Jobs: Green Jobs - An estimate of the direct employment potential of a greening South African economy (2011)
Amount of Green Public Procurement	Percentage of yearly procurement, using the share of environmental criteria in relation to the city administration's total annual procurement.	5.03%	2019/20	2019/20 Medium Term Revenue and Expenditure Framework for the City of Tshwane (2019)
Innovation				
Innovation hubs	Number of innovation hubs within the study city (public or private)	7	2019	City of Tshwane (2019)
Accessibility of open datasets	To which extent the open city data is accessible and user-friendly.	250	2019	Search engine: Google Results
Research intensity	Research and development spending as a percentage of city's gross domestic product.	0.0000432%	2017	IHS Global Insight (2017)
Data concerning the profile of City of Tshwane was gathered from the World Population Review, the reason being it was the most recent information. *Data is unavailable on city level, thus data is presented on a national level.				

Table 5: Calculated Key Performance Indicators for Tshwane

4.2 Results discussion

The testing was carried out as comprehensively as possible concerning the city scale assessment. For the city level evaluation, 32 Key Performance Indicators were assessed within the City of Tshwane, where possible. For one planned KPI (“Brownfield use”) the data was not available and only two planned KPI figures were collected on a national level, instead of a city level, which were (“Certified companies”) and (“Digital literacy and ICT”) due to the lack of measured information. There are various reasons for data not being available and it is not limited to only the lack of resources. It was clearly observed that the City of Tshwane has a range of action plans and goal oriented frameworks - however the City lacks recent real data figures that should be measured and assessed by city authorities. Figures are mostly targets and goals to be reached, without stating what the actual current situation is. It should be noted that Tshwane’s data is mostly estimates and various departmental documents state contradictory numbers for the same KPI - therefore results of this project are estimates calculated with the most recent datasets and those that could have been validated through repetition.

The time required to gather the data and calculate the KPIs was between 60 minutes to 90 minutes for each KPI, which could be due to the level of aces and availability of public data. Although, for some indicators it took much more time to find the right source, which could be validated through repetition. Thus, the amount of active work could be allocated to an hour and 30 minutes, and the other was made up of waiting for responses from various organisations and city departments. Data was further limited where the available data did not fit the specific KPI, regarding units or formulas. For example, water consumption was indicated within most public sources as domestic consumption. Realistically, KPIs cannot all match throughout cities with the specific *EUROCITIES CITYkeys* definitions, units or formulas, no matter how common or simple.

Referring to the individual KPI results, it is observed that some are much lower than expected, because the City of Tshwane includes vast rural areas and smart city measurements are only applicable to initiatives implemented in the city space. Therefore, the city surroundings should be kept in mind when including the city surface area, for example the low percentage of the number of bus stops within the city area that provides access to public transport. Implementing bike routes and lanes have been city goals since the 2008 Integrated Developmental Plan for Tshwane (City Of Tshwane Metropolitan Municipality, 2008). Nonetheless, the City has only been implementing them within recent years, and the length covering the city surface is extremely low, in comparison to the European international standard (Bosch, et al., 2017).

The City of Tshwane's safety and wellbeing indicator figures are up to standard, however it is the quality of those services that are not measured by the indicator that are troublesome and challenging for the public. Furthermore, not all incidences are reported and local departments are challenged with major backlogs. Environmental education programme data was challenging to obtain, since it does not fall within the curriculum of Tshwane public schools and therefore it was necessary to assess private organisation partnerships with schools. Green recreational space was measured using the CalcMaps online application with data retrieved from the City's urban planning departments, which included only city-owned or maintained land. It should be noted that the quality of the spaces are not taken into account. The African Green City Index was utilised to indicate the overall environmental performance of the City of Tshwane. The document is comprehensive and well researched, however measured KPI data within the document was captured quite a while back, the latest figures are from 2010, thus the data should be updated to improve accuracy (Economist Intelligence Unit, 2011).

City of Tshwane's energy consumption and greenhouse gas emissions are high in relation to the city surface and population. In addition, mitigation measures are minimal and renewable energy policies are mostly in the tendering phase (Miller & Spoolman, 2011). From previous indicator data, it is indicated that energy consumption is decreasing per capita and the use of renewable sources are slowly increasing. Indicators within the category of materials, land and water indicates to which extent the City of Tshwane's population effects available natural sources. The table indicates that the City is exacerbating its environmental performance and sustainability through increasing consumption (African Union; Economic Commission for Africa & African Development Bank, 2018).

Air pollution within Tshwane needs to be monitored more frequently and be made available for public knowledge, for the purpose of improving environmental awareness. More frequent and improved assessments also lead to improved capacity building for mitigation. In addition to pollution and waste indicators, according to the SACN Programme: Waste Management (2014) figures; waste per capita is reducing annually, having thus an improved impact on the urban environment. However, the percentage of waste being recycled from 2011 to 2019 continues at the same rate, without any improvement (Department of Enviromental Affairs, 2010). The City of Tshwane includes minimal large water sources and green protected areas are small in comparison to the amount of land available for development. The number of threatened species within the Bioregion are being kept low and controlled through environmental legislation (Holness & Skowno, 2016).

Unfortunately, the share of companies located within the study city with ISO 14001 certification was unavailable and data could only be captured for South Africa. Due to the current environmental crisis being worsened by environmental unfriendly industries, it is of utmost importance that the percentage of companies with ISO 14001 certification is rapidly increased. The amount of jobs associated with environmental service and the amount of green public procurement are extremely low compared to the total amount of jobs and public spending within the City of Tshwane, thus for improved environmental sustainability this needs to be increased (CSIR, 2019). Finally concerning innovation, the City of Tshwane is the front-runner in research and development within South Africa, due to the fact that an estimate of 90% takes place in Tshwane. Thus, Tshwane includes the Smart City component of innovation as a countrywide hub of learning and research. Even though the city conducts large amount of research and development projects, funding is predominantly sourced from private organisations. Therefore, the City needs to identify the lack of public funds for innovation, in order to address the constraint and have the ability to develop into a Smart City.

Current data availability was found to be an issue within the City of Tshwane when applying the *CITYkeys* KPIs, even though KPIs are quick to calculate. The data collection process was burdensome concerning some specific indicators possibly due to the fact that the smart city topic is wide and integrates various different sectors, which are organised in different city departments that regularly do not collaborate. Therefore, it was necessary to collect some data from sources outside the city organisation (i.e. national or regional sources or private companies).

In conclusion, on a city-level the project at hand provides information that could guide policy decision-making and indicates opportunities and gaps in areas associated with the smart city. The research question is answered and discussed in Section 4.4. The research objective of the key performance indicator approach has been achieved - a transparent performance evaluation framework for the City of Tshwane has been developed and validated. For the purpose of formulating recommendations for the integration and application of the performance system within the city's decision-making processes and also providing a platform for the engagement of stakeholders in identifying and exploiting opportunities for the City.

4.3 Approach significance

While the *EUROCITIES CITYkeys*' Key Performance Indicator (KPI) framework was developed to compare European cities with one another, it was found that it could also be applied to various international cities with similar assessment objectives (Bosch, et al., 2017). Although, it needs to be acknowledged that cities are unique and have their own aims and priorities. Due to

these specific priorities and aims within a city, it is rationale to focus only on evaluating certain available and most relevant Key Performance Indicators (Huovila, et al., 2017). These observations made by the *CITYkeys* framework have led to the conclusion that a flexible approach in applying the *CITYkeys* KPIs is allowed and often highly recommended. Nonetheless, a holistic and comprehensive assessment of all available resources are still encouraged, because it would result in a holistic assessment of all the main aspects of a Smart City (Bosch, et al., 2017). Cities vary from one another according to their size, population density, economic level, geographical location, technologic maturity, climate conditions and social structures, which all have an impact on relevant indicators (Kankaala, et al., 2018).

For this study, it was assumed that quantitative KPIs are more objective and valid in our local context compared to information from qualitative assessments. Due to the flexible approach, the research boundary is allowed to be implemented. The framework was applied for own purposes, therefore the flexible approach further allows interpretation of KPI definitions, as stated by the *EUROCITIES CITYkeys* report. The *CITYkeys* indicator framework should be utilised in an expert based assessment, similar to most frameworks (Huovila, et al., 2017).

The *CITYkeys* framework is applicable for the following practices (on city-level):

- City management
- Setting quantitative targets for a city's smart city strategies.
- Setting aims for cities monitoring progress systems.
- Input for decision-making processes of new projects, guiding existing projects, and evaluating performances of past implementations.
- Evaluating cities on operative level, strategic level, or policy decision-making.
- Users; i.e. metropolitan observatory, governmental departments, environmental planners, project managers, urban planners and local authorities.

It was found that there is a great need for the City of Tshwane to develop a centralised database for better application and implementation of the *CITYkeys* framework. This could lead to better evaluation and monitoring systems within the city, to improve sustainable development. This is a lot to ask and much work on this domain will be necessary, however it would greatly improve efficiency of data collection, exploitation and management in the City. Furthermore, it will improve the significance of the approach at hand, to measure the City of Tshwane's smart city level and to identify in what way this contributes towards the city's environmental sustainability.

4.4 Answer and conclusion

The research question to be answered from the above is the following;

- How does the City of Tshwane compare to the Smart City measure of European Cities?

On a city-level the research project at hand provides information to guide policy decision-making and indicates opportunities and gaps in areas associated with the smart city. The research objective of the key performance indicator approach has been achieved - a transparent performance evaluation framework for the City of Tshwane has been developed and validated. It was found that the European indicator framework could be considered more of an evaluation guideline than a final fixed framework, because of the different conditions and practices within a country. Furthermore, cities are unique regarding their individual existing datasets. Thus, when applying the KPI framework it was modified locally to improve relevance for the assessment and to answer the overall research question (Bosch, et al., 2017). When completing the *CITYkeys* city indicators, an extensive knowledge base was formulated with further inclusion of external expertise. The following figure indicates and summarises how the application of the above framework achieves the project objectives.

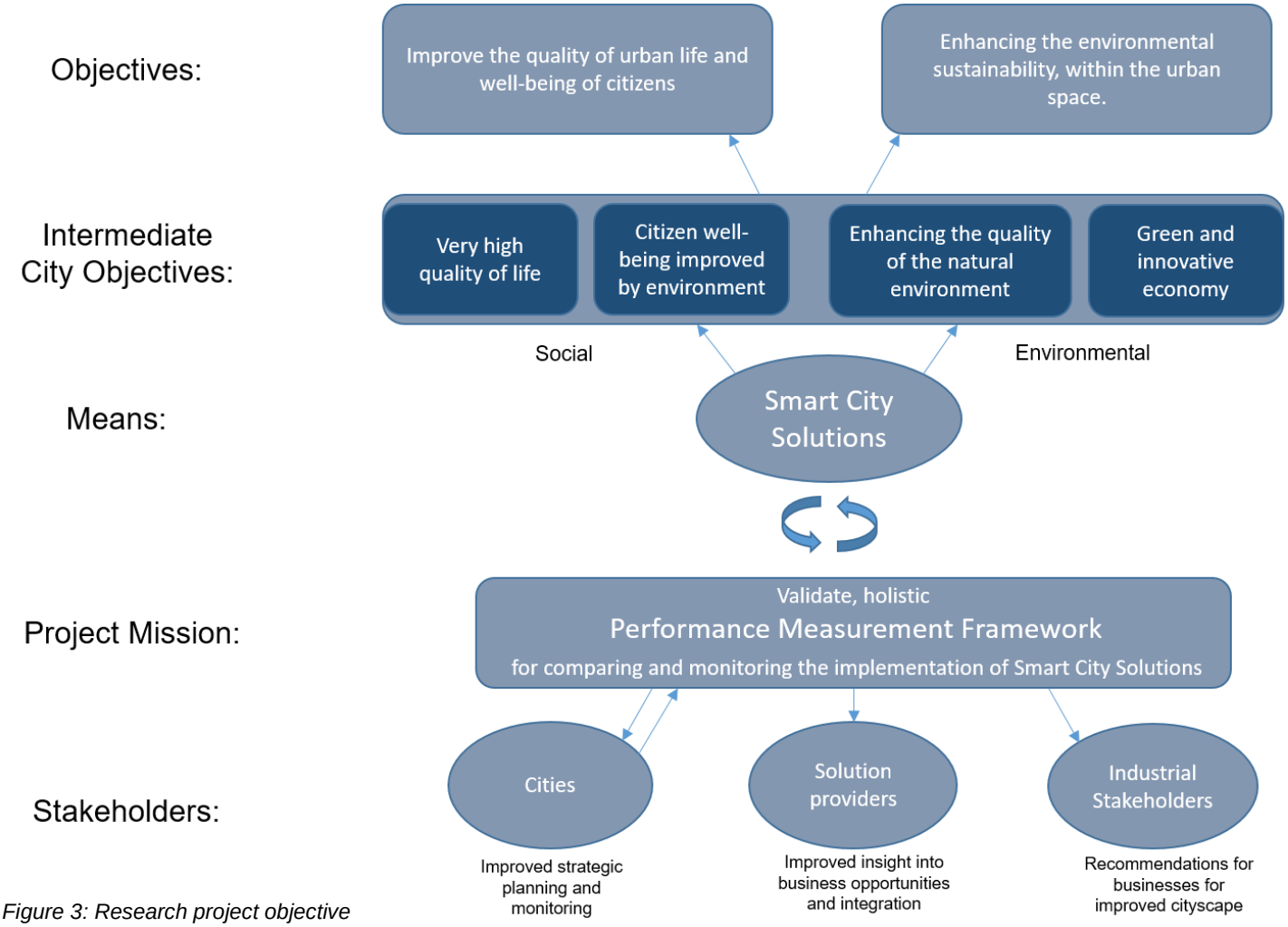

Figure 3: Research project objective

Concluding the analysis of the *EUROCITIES CITYkeys* Key Performance Indicator framework applied to the City of Tshwane, it was identified that Tampere City within Finland is the most appropriate city for comparison. Tampere was selected among the five cities that were tested in Europe by means of the *CITYkeys* performance measurement framework. The five test cities included – Zaragoza, Vienna, Zagreb, Tampere and Rotterdam. The concrete case study cities functioned as validation concerning the indicator framework in its developmental stage (Huovila, et al., 2017). The urban space of Tampere has a population of approximately 250 000 inhabitants, compared to the City of Tshwane the population is relatively smaller. Tampere strives to become a carbon neutral city by 2030, through the implementation of various smart city initiatives and projects on city-level. Tampere is a suitable example of a city improving and achieving environmental sustainability through smart city projects and city-level initiatives (Dimitrova, 2019). The case city serves as confirmation that the measured Smart City level of a city contributes toward the city's environmental sustainability, measured by the *EUROCITIES CITYkeys* KPI framework. Therefore, initially answering research question 2 partially of the research project that is;

- Does the measured Smart City level of Tshwane contribute towards the city's environmental sustainability, and if so how?

On the subject of Tampere, the *EUROCITIES CITYkeys* KPI assessment was conducted mainly for the purpose of an evaluation on city level, which is similar to the evaluation applied to the City of Tshwane. The assessment tool was also applied to achieve the objective of reaching different management levels, therefore operational and strategic, and politicians that further include operative level managers and city managers. Municipal councillors, mayors and vice-mayors are referred to as politicians. Thus, the tool relates to engagement on the city's strategy. Tampere also prioritised the most comprehensive use of the city scale assessment tool and had similar long-term objectives than that of Tshwane's assessment (Huovila, et al., 2017). The city of Tampere's objectives included;

- Developing, adopting and improving the KPI measure on primarily sustainable urban innovation and development.
- Further develop and improve the knowledge management system of the city, in addition to the ecosystem for collecting data.
- Finally, exploiting results during the planning process of new city strategies.

Tampere's city scale evaluation was carried out as comprehensively as possible and most of the data necessary was for quantitative KPIs. Tampere calculated 39 KPIs, whereas 32 KPIs were calculated concerning Tshwane, also focussing on quantitative KPIs (Huovila, et al., 2017).

However, for certain KPI calculations Tampere had automatic dataset readings available for their assessment, where Tshwane's datasets are restricted for the public (SACN, 2016). Tampere's data was similarly restricted due to unavailability of resources or the reason being that the effort was too great for data collection. Thus Tampere was unable to collect data for 9 KPIs including – green jobs, congestion, native species, local food production, grey and rain water use, water exploitation index, domestic material consumption, digital literacy and domestic freight transport fuel mix (Huovila, et al., 2017). This indicates that the KPI tool needs to be adjusted according to the local city context and should be interpreted according to internal definitions of indicators (Bosch, et al., 2017).

Tampere is similar to Tshwane, in relation to being one of the fastest developing cities in Finland, however Tampere's investments are much more heavily allocated to smart urban developments (Dimitrova, 2019). This difference is noticeably due to Tshwane's restricting developmental challenges, such as the increasing unemployment rate and the City's larger population of which the greater number people living under the breadline (CSIR, 2019). Tampere strives toward environmental sustainability through the implementation of various smart city projects, all of which have a city scale effect. Tampere is an energy-wise city evident by its efforts of collecting data from buildings and used as common platforms to integrate services with energy circumstances. Additionally the City has implemented a real-time energy service data platform, which increases the ability of the City to exploit demand response solutions and facilitate virtual power plant trials (City of Tampere, 2019). This lesson learnt from Tampere could be vital for South African cities, due to the current energy crisis experienced. In addition to this, Tampere's international STARDUST project utilises data to address challenges associated with sustainable mobility, energy consumption, environmental sustainability and construction, for the purpose of creating a more sustainable city (Kankaala, et al., 2018). From 2017 to 2020 projects have been implemented to advance the environmental quality and sustainability of the cityscape of Tampere, which includes – electric bus lanes of which energy consumption is strictly monitored, intelligent lighting projects that control outdoor lighting to increase safety and decrease energy consumption and also the Green Wave Optimization Mobile Application (GLOSA) was tested to reduce unnecessary traffic congestion for the purpose of decreasing greenhouse gas emissions. The City of Tampere is responsible and accountable for the implementation of these projects (Dimitrova, 2019). These type of projects, such as the international STARDUST project, are not only being implemented in Tampere, but also within cities in Spain, Italy, Greece, Czech Republic, Northern Ireland and Romania. Where similar pilots are being run in transport, energy, ICT utilisation and construction (City of Tampere, 2019).

Tshwane can learn from Tampere's sustainable neighbourhoods that are implementing projects with the objective of creating carbon-neutral partnership models, where material circulation for urban growth flows in the regional economy as resource wise and secure as possible (Kankaala, et al., 2018). The project further addresses urban food security and waste and by-product streams, categorised under the titles of materials, land and water, waste and pollution of the *CITYkeys* KPI tool.

The projects mentioned above indicate the importance of a central reliable foundation of data for the purpose of guidance and exploitation. In conclusion, the *EUROCITIES CITYkeys* KPI assessment provides a starting point for achieving a smart city that is environmentally sustainable (Bosch, et al., 2017). It is ironic that City of Tshwane states to become a Smart City, however there is no existing central data platform and in certain sectors there are not even existing data due to lack of monitoring and evaluation. The belief would be that in order to improve the above assessment on the level of City of Tshwane it is vital to develop a centralised data publishing, storing and management system for the purpose of exploiting and localising current available city data. The system could be further advanced by standardising the dataset formats to enhance data exploitation opportunities (Huovila, et al., 2017). This would allow for improved efficiency in processes such as reporting, coordination, and management for smart city related interventions, which finally allows for competiveness with the European standard and enhances comparability. Although, being within a developing country and challenged with numerous constraints, the City of Tshwane has a very long road ahead to achieve this type of transformation (SACN, 2016).

5. CHAPTER FIVE: SYSTEMATIC LITERATURE REVIEW RESULTS

5.1 Purpose of findings

The qualitative approach of the systematic literature review, examined the keywords ‘smart city’ and ‘environmental sustainability’, directed at the contributions of smart city initiatives made to environmental sustainability within an urban setting. The adjacent literature review’s purpose of findings are to expand what was found during the key performance indicator approach of the study area. The evaluated Smart City level above provides the overall picture of the study area, where as for the literature review approach zooms into the picture, for a more in-depth look at the relationship between smart city initiatives and environmental sustainability.

Smart city and environmental sustainability concepts create responsiveness of the use and production of natural resources necessary for commercial, industrial, recreational, transport and residential practices (Goonetilleke, et al., 2014). This is directed towards improving environmental conservation, concerning the utilisation of natural resources, within smart cities where sustainable urban development is supported (Komninos, 2016). It should also be acknowledged that various literature studies in their research emphasise the concept of ecological cities. The concept is closely linked to the research question at hand and supports the relationship between the terms ‘smart city’ and ‘environmental sustainability’. This specific concept was developed and encouraged in 1970, as a part of the agenda on sustainable development (Yigitcanlar, 2016).

As previously mentioned, the smart city concept is relatively new. It should also be noted that the concept could be better understood as the successor of a digital city, sustainable city and information city (Yigitcanlar, 2006). It was concluded, during the systematic literature review that the concept of a ‘smart city’ was more frequently used after 2013, when the term exceeded frequencies of citations of alternative concepts together with the sustainable city concept (Marsal-Llacuna, et al., 2015). Even though a number of authors have various definitions and conceptualise the terms of ‘smart city’ and ‘environmental sustainability’ differently, these definitions frequently overlap and are seldom contradictory.

Marsal-Llacuna *et al.* (2015) stated, that the assessment of a smart city needs to consider present and past practices of liveable and environmentally sensible cities, incorporating quality of life of citizens and sustainable practices, additionally to the composition of technological factors. Therefore, the research project at hand is validated by this statement. The term sustainability denotes the relationship between social, environmental, and economical sustainability perspectives from a selection of indicators of each component (Ahvenniemi, et al., 2017). It is accepted that these three issues should be addressed when referring to

sustainability; however this study concentrates mostly on one of the three to answer the research question. Pertaining to this specific study, focus is drawn to environmental sustainability. Thus, indicators that are mostly utilised above include - waste generation, pollution and the consumption of energy and water. Furthermore, it is of utmost importance to overall strive towards a city that is liveable and promotes the wellbeing of its citizens, therefore social indicators are also included such as a greener environment and social equity (Jong, et al., 2015). For improved understanding of the smart city concept and how it contributes towards environmental sustainability it was necessary to identify how it functions in practice, by applying the above key performance indicator approach to the City of Tshwane and then further expand our knowledge on the topic through the literature review approach.

5.2 Reviewed literature

Literature	Summary	Model	Aim
Kramers, A., Höjer, M., Lövehagen, N., & Wangel, J. (2014). Smart sustainable cities – Exploring ICT solutions for reduced energy use in cities. Environmental Modelling & Software, 56, 52–62.	The analytical framework intends to offer an improved understanding of the manner in which ICT investments could contribute towards reducing energy consumption, on a city level. To be utilised by ICT companies, regional and city authorities and researchers.	Analytical Framework	The paper indicates the environmental sustainability opportunities that arise through the implementation of ICT as an enabling technology within a city.
Tan, S., Yang, J., Yan, J., Lee, C., Hashim, H., & Chen, B. (2017). A holistic low carbon city indicator framework for sustainable development. Applied Energy, 185, 1919–1930.	The indicator framework provides 20 quantitative indicators for seven categories for the purpose of achieving a low to zero carbon city, through analysing the progress of low-carbon developments within cities. The categories include –waste, water, urban mobility, environmental and	Indicator Framework	The indicator framework was developed for the purpose of evaluating developments of low-carbon cities, through the application of advanced technologies, from various perspectives and covered by different categories.

	carbon, living and social, energy patterns, and city economic development.		
Tsolakis, N., & Anthopoulos, L. (2015). Ecocities: An integrated system dynamics framework and a concise research taxonomy. Sustainable Cities and Society, 17, 1–14.	The system dynamics methodological framework proposes to assist local governments, managers and decision-makers to adopt and design effective and efficient policies for assessing and monitoring sustainability of environmental cities.	Holistic System Dynamics Methodology Framework	The article aims to address the issue of the eco-city paradigm assessment, through the application of a multi-method approach.
Zhou, N., He, G., Williams, C., & Fridley, D. (2015). Elite cities: a low-carbon eco-city evaluation tool for China. Ecological Indicators, 48, 448–456.	The tool presented by the paper assesses progress of 33 key indicators, representing priority issues within 8 categories. The tool is convenient, and assumed efficient, for local city governments to define the comprehensive concept of a low-carbon eco-city and measuring the development of city efforts toward this objective.	Elite Cities Tool	The framework is applied and measures progress, through an excel-based tool. The tool achieves the objective of the paper by packaging key indicators, indicator explanations, indicator benchmarks, function of calculations and data recording instructions.
Zygiaris, S. (2013). Smart City Reference Model: assisting planners to conceptualize the building of Smart City Innovation	The article presents a constructed planning framework, namely the Smart City Reference Model. The objective of the framework is to	Smart City Reference Model	The model can be applied and adopted in a variety of smart city paradigms, thus supporting broadband, urban and green

Ecosystems. Journal of the Knowledge Economy, 4(2), 217–231.	analyses the characteristics of the smart innovative ecosystem, to explain the association between smart city notions and the green environment. Through integration of green, instrumented, interconnected, innovative, and intelligent layers.		economies. The model further aims to address global environmental sustainability challenges, through the paradigms, at a local context.
Hu, M. C., Wu, C. Y., & Shih, T. (2015). Creating a new socio-technical regime in China: Evidence from the Sino-Singapore Tianjin Eco-City. Futures, 70, 1–12.	The model presented by the paper promotes the cluster theory, which suggests a compact and connected city, for a minimal impact on natural resources. To achieve this objective, it is encouraged that neighbourhoods and city hubs are closely interlinked by means of grid networks, connected transportation, and economic ties.	Eco-City Model	The model promotes the development of a new socio-technical organisation that is reliant on ecological and green sustainability systems. Through this the paper indicates that the increase of the scale of urbanisation and its adaptation into the Eco-City Model will facilitate a city to develop as a global pioneer.
Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N., Meijers, E. (2007). Smart cities - Ranking of European medium-sized cities. Vienna University of Technology.	The article captures the perspectives of medium-sized cities for development. These assets are identified by using city rankings as a tool. Rankings are quite common, but do vary according to methods or approaches. Due to the variations, the paper explains that this is due to	Smart City Rankings Tool	The smart cities ranking model, proposes a modern assessment on medium-sized cities in Europe and how they differ and compare with one another, according to their smart advantages and disadvantages. The illustration of differences

	different interests behind rankings and therefore it is common that a city will be ranked differently compared to other rankings. The smart cities ranking is built on a holistic set of indicators. The approach facilitates an in-depth analysis for each city, due to the large number of indicators and the comprehensive definition of each characteristic.		further allows elaborate and specific perspectives of development and also strengths and weaknesses are identified in a comparative way for the considered city. This is proven useful for planning processes to achieve smart city development for the purpose of improving sustainability within an urban area.
Götz, G., & Schäffler, A. (2015). Conundrums in implementing a green economy in the Gauteng City-Region. Current Opinion in Environmental Sustainability, 13, 79–87.	The study analyses in what manner green economy strategies face challenges that constrict the thinking of future development paths, which in turn threatens to cultivate a regional economy that is extremely unsustainable. In addition to this, the paper reviews how the strategy procedure produces a hierarchy of green economy definitions.	Policy Review	The paper analyses the situation as it is locally, for the purpose of forming an improved understanding for the way forward on a regional level. The paper indicates that the concept of green economies and their development process needs to be handled with care in order for implementation to take place correctly to enhance sustainability.
Lazaroiu, G. C., & Roscia, M. (2012). Definition methodology for the smart cities model. Energy, 47(1), 326–332.	The model applies an approach that is based on ambiguous logic for indices. The model is proposed for computing smart city indicators. Although, it is the	The Smart City Indices Model	The paper provides a starting point for policymaking processes. Concerning discussion between stakeholders, including participation of

	opinion of the author that the indicators chosen contain too high amount of information and are not homogenous.		citizens, on final decisions of measuring tools adoption and best suited assessment options.
Yigitcanlar, T., & Lee, S. H. (2014). Korean ubiquitous-eco-city: A smart-sustainable urban form or a branding hoax?. Technological Forecasting and Social Change, 89, 100–114.	The U-Eco-City model is an eco-technology and ICT implementation. The principle foundation of the model is to provide citizens, tourist, and workers with an increased quality of life and excellent urban spaces, with low-to-zero adverse influences on the environment. The model is supported by advanced technologies.	U-Eco-City, Korea City Model	The paper aims to test the basis of a U-Eco-City and answer the question of it being just a branding hoax or an impressive sustainable and smart urban layout that establishes the ideal contemporary city model.

Table 6: Reviewed literature for analysis

5.3 Results

The research approach was built on advanced academic literature on the concept of smart cities and its contribution towards environmental sustainability, including the knowledge of experts relating to the environment, sustainability, smart initiatives, infrastructure and services, and smart cities. The ten articles indicated above, present research on frameworks, models or tools formulated according to smart city and environmental sustainability objectives. The articles do not present similar tools, frameworks or models and apply different approaches. Therefore, it is important to take note of the models, tools and frameworks that utilises ICT, which includes – the analytical framework, holistic system dynamics methodological framework and the model for calculating smart city indices. Furthermore, those that that include categories or indicators, which could be applied for smart city analysis consist of – the elite cities tool, the model for computing smart city indices, evaluation of low-carbon city framework, the conceptual framework

and eco-city model. It was concluded that the model applied for calculating smart city indices is the only model that utilises both the indexes and ICT for smart cities. The indexes propose measurement for environmental sustainability performance for general application.

The brief overview of literature above indicates various methods and approaches that have been developed in relation to smart cities and its influence on environmental sustainability. It is however difficult to reach a consensus on which approach is most applicable to determine the extent of environmental sustainability of a measured smart city. It was noted that from the above literature study that there exists a vast amount of definitions associated with smart cities and environmental sustainability concepts, which could lead to incorrect interpretation for the purpose of answering the research question (Yigitcanlar, 2006). Therefore, the search was limited to the two specific terms, to better answer the research question, without adding to the confusion concerning the branding of the two different concepts.

The tabled articles provide discussions and information on various concepts, such as smart cities, environmental sustainability, eco-towns, sustainable urbanism, and green cities. A cloud of tags was generated from the studied literature, indicating the core topics of the selected articles and how they relate to one another in the following figure, Figure 4.

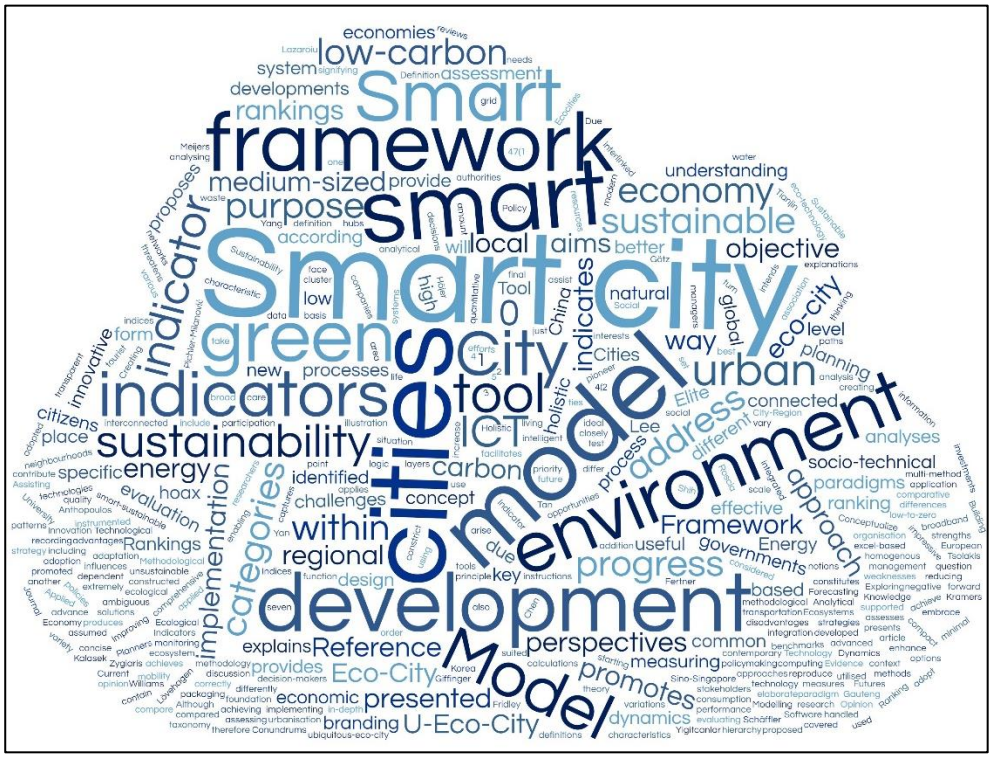

Figure 4: Cloud of Content

The articles include, solution studies that are proposed in smart cities and green economies, or mathematical models to build data bases for evaluation and monitoring of cities, and some articles also provide cities with detailed guidelines. The search included the keywords ‘smart city’ and ‘environmental sustainability’ stretches across a full range of disciplines, including – social sciences, sustainability studies, natural sciences, humanities and urban studies. The material of the reviewed literature studies was analysed and the year of publications were identified. The reviewed articles were issued between 2007 and 2017, by analysing the years of publication of the articles it was recognised that the ‘smart city and environmental sustainability’ subject matter only truly gained momentum and increased in popularity during the past 5 years.

With reference to the City of Tshwane, it was found that addressing the environmental characteristics of smart cities resulted in more of a political discussion, with regards to innovative solutions and international resolutions in the search for solutions for complex city challenges. However, the concept of a ‘smart-eco city’ adequately describes the contribution of smart city initiatives towards the city’s environmental sustainability. The concept promotes the ecological health of a city, through the use of advanced technologies and assessment systems to ensure environmentally and economic efficient industries, which are responsible for a functional living cityscape and a harmonious systematic culture (Yigitcanlar & Lee, 2014). The search keywords used were ‘smart city’ and ‘environmental sustainability’, in case studies similar to the City of Tshwane context or of which the City could gain and apply knowledge learnt from other smart city initiatives.

In conclusion, it was found from the above literature review that smart city technologies and implementations create the setting for possible significant changes towards environmental sustainability. Insight was provided by the review into some of the consequent debates, critiques and challenges concerning the research topic. The adjacent literature review approach expands what was found during the KPI approach of the study area (Ahvenniemi, et al., 2017). The objectives of the literature review approach were achieved, by establishing the relationship between smart city indicators and its environmental performance. This could also measure progress in achieving policy objectives. This approach also allows for a way forward and functional strategy indication in the long-run. This literature review study also provides vital insights for academics studying the topic, as well as governmental authorities considering to apply the findings into practice within their cities, for the purpose of enhancing the sustainability of the natural environment within an urban setting.

5.4 Answer and conclusion

The research question to be answered from the above is the following;

- Does the measured Smart City level of Tshwane contribute towards the city's environmental sustainability, and if so how?

Harrison et al. (2010) justifies that smart city practices reduce environmental impacts and promote environmental sustainability, through the adoption of city figures from energy use statistics, traffic management, security and enhancing municipal service effectiveness. From a range of literature studies, it is indicated that the increase in importance in smart cities and interrelated concepts are linked to various influences such as – climate change, globalisation, increased competition, increasing urbanisation, and natural resource scarcity (Ahvenniemi, et al., 2017).

As stated by Chattopadhyay and Dhingra (2016), a smart and environmentally sustainable city achieves certain objectives, which are applicable to identify how the measured Smart City level of Tshwane contributes towards the city's environmental sustainability. The objectives should be achieved in a resilient, accessible, scalable, reliable, and also an adaptable manner. Goals that should be achieved by a smart and environmental sustainable city includes – improved living standards of citizens, established and efficient regulatory governance tools for impartial policies, mitigation between environmental and climate change challenges, ensured economic growth and employment opportunities whilst securing an environmental conservation. Efficient service delivery should be ensured together with infrastructure that consists of water supply and drainage, public transportation, waste removal, ICT and other utilities (Dhingra & Chattopadhyay, 2016). Regarding this concept, ICT includes all related smart tools and telecommunication technologies available to distribute information, functioning as a private and public services facilitator, and facilitating the management, integration and implementation of the interventions recommended by relating thematic sectors, which contribute towards improving overall urban environmental sustainability. Smart technologies include all practices and technologies that lead to the improvement of resource efficiency, consumption, and energy production.

It is critical to note that indicators proposed above are frequently not tracked in many cities, specifically those within developing countries, which includes the City of Tshwane (CSIR, 2019). This lack of uniformity of approaches and concepts regarding smart environmental cities could lead to excessive heterogenic indicators and methods for the purpose of measuring environmental sustainability performance. Furthermore, alleviation of urban and environmental challenges require robust citizenship and democratizing access to environmental data to enhance sustainable ecosystem management. From the above literature studies it was also

indicated that one must make reference to socio-environmental justice, regarding smart city initiatives. For example poor urban residents that do not have the technological means to participate in the smart city movement need to be included in alternative ways, for the purpose of improving their quality of life along with others. These social inequality risks could become entrenched through repetitive forms of smart city initiatives (Crawford, et al., 2014).

Even though these issues persist in the City of Tshwane, it was found that there exist a direct correlation among smart city implementations and the improvement of environmental sustainability, from international examples. Karen Bakker and Max Ritts (2018) specifies that environmental sustainability has the potential to be considerably transformed by smart city implementations, technologies and actions, which include innovative environmental and urban system monitoring systems. This is achieved, through the combination of data, communication technology, conventional monitoring technologies, key performance indicator frameworks, ICT and the Internet of Things (IoT), for example Environmental Sensor Networks (ESNs).

It was indicated from the literature review that there is not one specific definition that combines both concepts of 'smart cities' and 'environmental sustainability', thus in this research report reference was made to a particular definition that would be applied throughout the study to eliminate this issues. The following smart environmentally sustainable city definition was specifically applied – *"a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green" referring to urban infrastructure for environment protection and reduction of CO_2 emission, "interconnected" related to revolution of broadband economy, "intelligent" declaring the capacity to produce added value information from the processing of city's real-time data from sensors and activators. Whereas the terms "innovating", "knowledge" cities interchangeably refer to the city's ability to raise innovation based on knowledgeable and creative human capital"* (Zygiaris, 2013, p. 217). The definition is the foundation of the above literature study and the key performance indicator framework, where an index method was applied that contains indicators to measure environmental sustainability fixed in the conceptual framework and also suggests an approach to track progress of the City of Tshwane's environmental sustainability over time in accord with smart city interventions.

In conclusion, the study was conducted due to the increasing attention towards the subject of smart cities and environmental sustainability, from the year 2013 (Brilhante & Klaas, 2018). The literature review on the subject provides knowledge in the field, the exploration of practical and academic applications and elaborates on what was found during the key performance indicator approach of the study area. The results have led to the development of an initial smart

environmental sustainable city concept and an evaluation tool to be applied during policymaking and academic activities, for the purpose of supporting cities to become more environmentally aware. Key findings of the literature review were based on a specific pillar of the three pillars of the sustainability theory, which is the environment and includes energy, social wellbeing, infrastructure, compactness, urban planning, climate change, land distribution and greenery (Fu & Zhang, 2017).

To answer the research question, it is evident from various literature studies that smart city initiatives applied in all city activities facilitate the enhancement resource efficiency within a city. Consequently contributing towards enhancing the environmental performance, quality, liveability and sustainability within the cityscape. In order to achieve this, the Smart City level of a city needs to be measured and evaluated to establish a baseline from existing data and to indicate the current situation for a better way forward (Bosch, et al., 2017).

6. CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Research findings

6.1.1 Setting the scene

During the assessment of the study site, it was found that the current developmental, contextual, institutional, socio-economic, and built environment status quo, and its associated strengths, weaknesses, opportunities and threats, direct and inform the future developmental recommendations and interventions. It was found that the City of Tshwane has been developing unsustainably, largely due to the typical resource-intensive development path followed and the lack of adequate monitoring systems - inefficiencies are thus present across various sectors (City of Tshwane, 2013). It is thus crucial that the Smart City level of Tshwane is adequately measured and compared to international standards, to gain knowledge on the topic and to presumably contribute towards environmental health, international competiveness, and human wellbeing. The research questions addressed here thus identify all key aspects that play a role in this specific research environment. The research questions are structured as the following;

1. How does the City of Tshwane compare to the Smart City measure of European Cities?

2. Does the measured Smart City level of Tshwane contribute towards the city's environmental sustainability, and if so how?

An inside-out approach was applied to better understand the dynamics between smart city interventions, the measured Smart City level of Tshwane, and its impact on environmental sustainability. During the Key Performance Indicator assessment of the *EUROCITIES CITYkeys* approach, the inside dynamics were analysed between the City of Tshwane and relevant smart city initiatives. By using data from comprehensive open city data platforms to obtain standardised urban metrics from city software and desktop studies, municipal and departmental policy documents, companies with open access data, and the application of GIS software. In addition to this, data was collected from activities that have already taken place within the cityscape. With reference to the literature review approach and answering the second research question, the outside dynamics and relationship between smart cities and environmental sustainability was analysed and presented. A better understanding was gained of the interrelationship between the concepts. Thereafter findings were integrated from the two different research approaches.

6.1.2 The process

It is the opinion of the author that the application of the *EUROCITIES CITYkeys* Key Performance Indicators on city-level was the most applicable framework to adequately measure the City of Tshwane's smart city performance. Benefits of using the specific standard, includes the opportunity to compare worldwide cities, findings are supported by specialist and peer backing, and a comprehensive analysis of various indicators of a Smart City is provided. In addition, the opportunity to aim for a defined standard is provided, relevant international issues are covered, and opportunities could be exploited to enhance the case city's environmental sustainability through smart city initiatives. The testing was carried out as comprehensively as possible concerning the city scale assessment. However, it was found that that resilience is not addressed by the *CITYkeys* framework, where resilience is a vital component of a smart environmental sustainable city. This criticism is small compared to the various benefits of the *CITYkeys* framework, which includes – relevancy, the flexible People-Planet-Prosperity-Governance-Propagation structure of the framework, the division between city and project level approaches, the various accessible KPI assessment formats and guidelines, and the overall framework is well-received and answers to the needs of the city organisation (Bosch, et al., 2017). The research project findings indicate that the KPIs correspond satisfactorily with the key objectives of the study, thus the framework structure and selected indicators are well designed and can be validated in practice. Most of the city KPIs have been verified successfully in the City of Tshwane.

The main challenge relating to the applied framework was the collection of data, specifically to localise data and to gain access. There are a number of reasons for data not being available and it is not limited to only the lack of resources. It was clearly observed that the City of Tshwane has various action plans and target oriented frameworks, however the City lacks recent real data figures that should be measured and assessed by city authorities. Figures are typically targets and goals to be reached, without stating what the actual current situation is. It should be noted that Tshwane's data is mostly estimates and various departmental documents state contradictory numbers for the same KPI, therefore results of this project are estimates calculated with the most recent datasets and those that could have been validated through repetition.

Based on the assessment applied to the City of Tshwane, some modifications were made to the *CITYkeys* KPI definitions and calculations, as suggested by the EUROCITIES guidelines. However, the detailed performance indicator testing conclusions are indicated in Appendix A. It is important to note in the research report, where interest is indicated to compare the City of Tshwane with international cities, it was done briefly and mostly to learn from alternative smart city practices, instead of comparing performances. Since it was not

the original aim of the *CITYkeys* KPI framework and tools to be applied for the purpose of inter-city comparisons, thus additional development and design is necessary to support this objective (Huovila, et al., 2017). Cities cannot be easily compared numerically with the *CITYkeys* city assessment due to various city differences, such as climate, energy consumption requirements, legislation and local policy variances. Therefore it is encouraged that cities develop their own target values to implement the tool and KPI framework (Bosch, et al., 2017). On a city-level the project at hand provides information that could guide policy decision-making and indicate opportunities and gaps in areas associated with the smart city. The research objective of the key performance indicator approach has been achieved - a transparent performance evaluation framework for the City of Tshwane has been developed and validated. For the purpose of formulating recommendations for the integration and application of the performance system within the city's decision-making processes and also providing a platform for the engagement of stakeholders in identifying and exploiting opportunities for the City.

After the smart city indicators have been applied and measured, the study continues to identify how this contributes towards the environmental performance of the City of Tshwane. The environmental sustainability contributions were assessed according to standards acquired from various peer reviewed literature studies. The second approach of assessing environmental sustainability contributions, according to standards and secondary data acquired from various peer reviewed literature studies, is generally applicable for qualitative research. The approach aims to analyse scientific studies that are relevant to the findings of the first research approach. The approach was applied to identify information about frameworks, models, tools and researchers, focusing on the two specific themes. The adjacent literature review approach expands what was found during the key performance indicator approach of the study area. The evaluated Smart City level provides the overall picture of the study area, where the literature review approach zooms into the picture, for a more in-depth look at the relationship between smart city initiatives and environmental sustainability (Iacono, et al., 2009).

It was found that environmental sustainability is most appropriately defined as improving or maintaining the integrity of life supporting systems on planet Earth (Moldan, et al., 2012). It is stated by Moldan, et al. (2012) that environmental sustainability, unlike the other two pillars of sustainability being societal and economic, is open for the development and utilisation for objectives that are founded in the biophysical assets of a system. Locally, the main objective is to maintain the required quality and quantity of the resources from the environment, which the urban community depends on and once reached to move beyond this objective (CEM,

2006). The literature review approach enabled the assembly of smart city and environmental sustainability paradigms into a conceptual holistic model. The review analysed innovative urban dimensions that correlate between smart cities, green cities, innovative ecosystems, intelligent communities, connected life, and social and environmental sustainability with urban development.

It was evidently difficult to recognise the value of smart city interventions, projects and activities, while identifying the causal effects on targeted environmental outcomes, even though a baseline was established to monitor progress. It should be noted that applying and measuring indicators of progress of smart cities is much easier than measuring the contributions towards environmental sustainable outcomes of the City of Tshwane. Therefore international examples were analysed in addition to various peer reviewed literature studies to indicate a cause-effect relationship, such as the City of Tampere (Caird, et al., 2016). When moving forward, local authorities need to recognise the complexities and challenges associated with the evaluation of smart city interventions, and proving the indirect and direct contributions towards environmental outcomes.

6.1.3 Finding the living urban sustainable environment

It was found from the literature review approach that smart city technologies and implementations create the setting for possible significant changes towards environmental sustainability. Insight was provided by the review into some of the consequent debates, critiques and challenges concerning the research topic. The adjacent literature review approach expands what was found during the KPI approach of the study area (Ahvenniemi, et al., 2017). The objectives of the literature review approach was achieved, which includes the establishment of a relationship between key smart city indicators and its environmental performance, which could be applied to measure progress and achieving policy objectives. In addition to indicating a way forward on application of smart city ideas to be adopted for the objective of enhancing the quality of the environment in the long-run.

There is a strong relationship among smart city implementations and the improvement of environmental sustainability. Karen Bakker and Max Ritts (2018) specify that environmental sustainability has the potential to be remarkably transformed by smart city technologies and actions for the better, combined with innovative environmental and urban monitoring systems, through the arrangement of data, communication technology, conventional monitoring technologies, key performance indicator frameworks, ICT and the Internet of Things (IoT). The smart urban environment study indicates the increasing demand for more

liveable, efficient, and sustainable urban developmental models. This sets social and environmental sustainability as the key focus of smart cities. The study at hand proves that a smart city promotes environmental sustainability within its urban space. When referring to interconnected economies related to the revolution of broadband, green urban infrastructure that protects the environment and reduces pollution and the promotion of intelligence by increasing the capacity to add value to information when producing real time data from assessments and sensors (Bakker & Ritts, 2018). The city raises innovation based on creative and knowledgeable human capital for the purpose of sustainability (Blewitt, 2008). Most importantly, although each of these conceptions add to a smart city vision, it all contributes significantly towards environmental sustainability and growth (Zygiaris, 2013). The design of the research project deals with city scale challenges, but could have an impact on the global environmental situation by reintroducing the protection of the environment as an important objective of urban policies throughout various cities.

It is evident that a sustainable productive environment, which provides a resource foundation, could be achieved through a Smart City. A sustainable economy is dependent on a sustainable flow of environmental resources, energy and materials, of which an economy system will fail without (Moldan, et al., 2012). In addition to this statement, a sustainable environment is independent and does not require the existence of either an economy or society, as proven in the wild in its own is a sustainable system (Blewitt, 2008). The study significantly emphasises environmental sustainability due to it being the only sustainability pillar that can actually stand independently. Therefore it could be concluded that environmental sustainability should be the model to compete with and not to add to its destruction. Smart city initiatives implemented to remove risks and raise environmental sustainability contributes toward sustainable socio-economic systems (Moldan, et al., 2012). Environmental sustainability could be described as a state of balance, interconnectedness, and resilience (Brilhante & Klaas, 2018). The urban space must provide for the natural environment to improve the wellbeing of its citizens (Rüde, 2006). A case is consequently made that smart cities contribute significantly favourable towards environmental sustainability. The current urban development movement should motivate urban managers, environmental planners, and academics to identify innovative methods to encourage urban and socio-economic growth with minimal environmental impacts and the sustainable use of natural resources.

6.2 Recommendations and intervention

6.2.1 Pathways to the urban sustainable environment

According to the study at hand, recommendations and interventions have been formulated to address the research problem and answer the research question. Interventions are proposed to indicate in what way the measured Smart City level of the City of Tshwane could contribute towards the city's environmental sustainability. It has been emphasized by Toppeta (2010) that smart city implementations increase sustainability and improves liveability of a city. Furthermore, Smart Cities combine diverse technological implementations for the purpose of reducing environmental impacts, whilst contributing to improve the wellbeing of citizens (Kushida & Zysman, 2009). Thus, it is vital that the Smart City level of Tshwane is measured to gain knowledge on the topic and to presumably contribute towards environmental health, international competiveness, and human wellbeing.

It could be recommended for the Smart City level of Tshwane that the development and validation of a transparent performance evaluation framework for the City should be established, through the application of the *EUROCITIES CITYkeys*' KPI framework and guidelines. This requires the integration and application of the performance system within decision-making processes of the city. The framework should be developed and applied in such a way that a platform is provided for the engagement of stakeholders in identifying and exploiting opportunities for the City of Tshwane. When applying the *CITYkeys* indicators the ultimate objective should be to promote rapid widespread, adoption and implementation of smart city services and solutions in order to achieve sustainable environmental goals within urban areas. Regarding recommendations on how the measured Smart City level of the City of Tshwane could better contribute towards the city's environmental sustainability, it is proposed that an improved relationship is established between key smart city indicators and environmental performance, and how this could be applied and integrated to measure progress and to achieve policy objectives. The study at hand provides a starting point and indicates a way forwards for the City of Tshwane, with reference to the adoption and application of smart city ideas for the objective of enhancing the quality of the environment in the long-run.

As to the overall research topic, it could be finally recommended to plan and develop the most appropriate city environment that can foster the dynamic interactions necessary to implement sustainable and adaptable smart city projects for the purpose of enhancing the quality of the natural environment and its sustainability. An operationally resilient and sustainable environment is created through rehabilitation and conservation objectives, technologies and implementations that maximise natural resource utilisation, the re-establishment of natural systems within an urban space, effective energy production and consumption, and finally the most appropriate use of technologies and materials, within a

suitable urban context (Rüde, 2006). Smart city interventions should be implemented to achieve subsequent environmental objectives that are reliable, resilient, accessible, adaptable and scalable. Interventions should strive towards increasing the quality of life for all citizens, the capacity to address environmental and climate change challenges, and improving the welfare of citizens by safeguarding access to community and social services (Marsal-Llacuna, et al., 2015). A sustainable and environmentally responsible approach for growth and development should be established to achieve intervention objectives, more specifically efficient and adequate service delivery of infrastructure and basic services, for example drainage and water supply, energy generation and supply, public transportation, telecommunication, education, appropriate waste removal and other utilities needs to be ensured by city authorities (City of Tshwane, 2013).

It is recommended that a smart city vision should achieve a sustainable city future by including the bigger picture of a sustainable smart globe. A city's innovation ecosystems, stakeholders, urban resources, utilities, infrastructure and services includes a triple helix complex. Thus, environmental and city master planning should include innovative features that provide for sustainable, green smart planet development, which is this study's focal point. The study also indicates some of the numerous approaches and methods that have been applied to evaluate and formulate guidelines for the implementation of smart cities. It should be noted that the various available approaches to evaluate smart cities and related issues, could lead to challenges when building a consensus on which measures and methods needs to be applied through cities to become smarter, in order to positively contribute to environmental sustainability. In addition to this, the existence of wide-ranging urban and environmental associated challenges within cityscapes have led to the formulation of numerous urban environmental and innovative city definitions, as mentioned above, therefore challenges could arise concerning adoption and acceptability (Campbell, 1996). Thus, it is important to recommend that a specific concept and set of objectives are constructed to implement urban initiatives that can affect the natural conditions.

It is recommended that the *EUROCITIES CITYkeys* KPI assessment provides a starting point for achieving a Smart City that is environmentally sustainable (Bosch, et al., 2017). Tshwane can learn from the City of Tampere, which have applied and tested the *CITYkeys* KPI framework recently. Lessons are also provided by the City of Tampere's sustainable neighbourhoods, which are implementing projects with the objective of creating carbon-neutral partnership models, where material circulation for urban growth flows in the regional economy as resource wise and secure as possible (Kankaala, et al., 2018). The city project further addresses urban food security, waste, and by-product streams, categorised as

materials, land and water, and pollution and waste within the above *CITYkeys* KPI framework. It was further found that in order to improve the above assessment on the level of City of Tshwane it is vital to develop a centralised data publishing, storing and management system for the purpose of exploiting and localising current available city data. It is recommended that the system should further be advanced by standardising the dataset formats to enhance data exploitation opportunities (Huovila, et al., 2017). This allows improved efficiency in processes such as reporting, coordination, and management for smart city related interventions, which finally improves competiveness with the European standard. Although, being within a developing country and challenged with numerous constraints, the City of Tshwane has a very long road ahead to achieve this type of transformation (SACN, 2016).

6.2.2 In today's news

It is ironic that President Cyril Ramaphosa (2020) states that Gauteng cities should develop into Smart Cities, even though there are numerous challenges that should first be addressed to achieve this objective. Such as the establishment of a central data platform and in certain sectors monitoring and evaluation and needs to be improved to improve data on current situations. As revealed at the SONA 2020, a new Smart City will be constructed at Lanseria, which falls under the City of Johannesburg Metropolitan Municipality, Gauteng. It is stated that the city will have space for 350 000 to 500 000 inhabitants, lead the way for green infrastructure across Africa and on an international scale, and will be 5G network ready (The Presidency, 2020). The process is managed by the Presidency Investment and Infrastructure Office along with provincial governments, and further includes the cities of Madibeng, Johannesburg and Tshwane. The innovative process is expected to self-fund bulk electricity, roads, sewerage, water and digital infrastructure, which will be the foundation of the new Smart City. It is declared by President Cyril Ramaphosa (2020) that the Smart City will ensure solutions that are cost effective for the State, transfer meaningful skills and create a higher potential for labour intensive jobs compared to conventional urban construction methods. Infrastructure will be implemented in Tshwane, Lanseria and Madibeng to support the smart city development (The Presidency, 2020). It is the opinion of the author that, instead of creating a completely new precinct, what we currently have in our urban spaces should be evaluated and assessed to be exploited for the reconstruction and implementation of smart city initiatives. Rather than isolating surrounding urban spaces and limiting smart resources to the new development. Through proper assessment and developmental urban planning, existing infrastructure could be utilised as the building blocks of a Smart City, instead of neglecting old precincts and reallocating fund away from

upgrades (Ahvenniemi, et al., 2017). This new innovative process could also have the potential to further diminish the natural environment, by developing untouched natural landscapes instead of focusing on brownfield developments to improve existing urban spaces (Watson, 2015). It is required that a new Smart City development enhances and protects natural features of the environment, such as water quality, energy consumption and the scenic amenity. It is vital to identify and ensure conservation of lands that are important for recreational, environmental and habitat linkages.

Due to the above city plans, it is recommended that the *CITYkeys* framework is utilised for the following practices:

- Setting quantitative targets for a city's smart city strategies and the evaluation thereof.
- Setting aims for cities monitoring progress systems.
- Input for decision-making processes of new projects, guiding present projects, and assessing performances of previous implementations.
- Evaluating cities on operative level, strategic level, or the level of policy decision-making.

Users of the *CITYkeys* framework should include the metropolitan observatory, governmental departments, environmental planners, project managers, urban planners and local authorities. Also including citizens, the *CITYkeys* KPIs could serve as a suitable engagement platform to promote awareness. Adequate public participation could be rewarding for policymakers, for the creation of innovative projects by applying co-creative dynamics. It is further recommended that the smart city assessment should be conducted by experts in the field and that a comprehensive knowledge base is required for the city performance indicator completion. This will allow clarity and standardisation of indicator definitions and more accurately calculated results (Huovila, et al., 2017). It is thus required to integrate and collaborate with a variety of experts from various city departments for a holistic application of the *CITYkeys* framework. Public funding plays a vital stimulating role for current smart city projects and development. The reallocation of public investments towards smart city initiatives should be promoted. For the reason being to support environmental sustainability and due to the fact that smart city implementations incorporate a very promising and solid business component, which could be capitalised into economic growth and job creation to return the public funds (Elgazzar & El-Gazzar, 2017).

6.2.3 Urban planning through environmental principles

The following points provide a general understanding and clarification of the direction and purpose of the research project. The Smart City level of the City of Tshwane could successfully contribute towards the city's environmental sustainability, through the implementation of following principles;

- Ensuring the capacity to adequately monitor and evaluate progress and development.
- Improving obtainable information for decision-making processes through indicators.
- Improving the level of understanding of non-linear development of complex city systems.
- Regarding different assessment scales, abilities to react, flexibility and local conditions.
- Maintaining ecosystem integrity through efficient natural resource management and de-coupling environmental stress from economic development.
- Developing nothing that will require the increase of future generation awareness, thus enhancing the quality of life through environmental and social interfaces (Brundtland Commission, 1987).
- Developing and delivering services and products that contribute to the triple helix of sustainability.
- Making environmental sustainability a key requirement in the production and service delivery sector, by reviewing environmental attributes of raw materials.
- Preserving biodiversity by selecting raw materials that sustain the biodiversity of natural resources.
- Enhancing open green spaces for the purpose of environmental awareness, recreational activities, and citizen wellbeing. In addition to, the promotion of open spaces that incorporated urban forests to function as carbon sinks, thus reducing air pollutants and improving air quality.
- Including environmental education programmes in school curriculums to improve current and future generation awareness.
- Certifying companies and green works functioning above branding and marketing objectives could have major compliance and positive impacts on the environment.
- Developing legislation that promotes brownfield developments above greenfield developments, to protect the existing natural landscape.
- Improving access to ICT and the Internet of Things (IoT) to expand the city's knowledge base. By bringing educational platforms to the people, it minimizes commuting to the city to educational hubs, therefore congestion and traffic emissions are also decreased.
- Allocating funds towards improving energy efficiency to decrease annual consumption, and promote the use of environmentally sustainable and responsible energy sources (United Nations, 2015).

- Improving regenerative capacity of natural systems, by keeping harvest rates of renewable sources within its capacity.
- In keeping exhaustion rates of non-renewable input resources to an absolute minimum.
- Designing and developing with recycling and reusing in mind to promote closed-loop systems for business and manufacturing processes, while reducing waste and emissions to zero.
- The human economic subsystem should be restricted to a level within the carrying capacity, which is more sustainable. The scale of the human economic subsystem could be described as technology *x* consumption per capita *x* population (Tushman, 2002).
- Waste emissions should be kept within the absorptive capacity of the receiving ecosystem, without undesirable degrading effects on vital ecological services or future waste assimilative capacities (Green City Index, 2009).
- Developing and implementing transportation modes that prioritise low environmental impact such as bike lanes, electric vehicle support systems and public transportation.
- Improving urban environmental occurrences through better governance, management and cooperation.
- Innovation hubs and research and development investments create opportunities for data-intelligent driven assessments with urban analytics, which should be incorporated to support the best practices of smart city implementations.
- Approaching all urban management and city development decisions with complete consideration of the effects on environmental sustainability, being the only sustainability pillar that stands independently.

In summary, to be able to incorporate the above principles into the development of a Smart City that achieves environmental sustainability, a rigorous assessment and reporting mechanism is recommended to support city decision-making. Therefore, the smart city evaluation framework should be developed in accordance with the needs of the study city and the framework needs to be developed according to expert and tested guidelines. The framework should be adaptable and flexible to reflect different city circumstances and complex city challenges, covering all the meaningful city indicators rather than having a constricted focus, and could be improved in response to new city mechanisms. Furthermore, current smart technologies create opportunities for data-intelligence driven assessments with urban analytics, which should be incorporated to support the best practices of reporting and evaluation (Caird, et al., 2016).

In conclusion, global constraints are faced by cities on a local level, while they are playing one of the greatest contributing roles of a sustainable smart Earth (Green City Index, 2009). Therefore,

master planning of cities need to include innovative characteristics that contribute towards the growth of a smart, green and sustainable planet, which is the focal recommendation point of this study. A collective understanding is provided in the study and should be applied among city stakeholder and smart city investment priorities. The outcome and general structure of this research project could be utilised by smart environmental and urban planners for the prevention of unsustainable developments. The research project could be further developed according to the socio-technical complementarities of the city and the general course of development. Therefore, the key performance indicator framework should not only be used for environmental sustainability, but could also be applied for economic prosperity, good governance, competitiveness, renewable resource opportunities, employment generation, social divides, poverty alleviation, and many more.

6.3 Conclusion

6.3.1 The environmental dimension of urban planning

It is vital that the Smart City level of Tshwane is measured, to gain knowledge on the topic and to presumably contribute towards environmental health, international competiveness, and human wellbeing. The importance of a central reliable foundation of data is indicated for the purpose of guidance and exploitation. The *EUROCITIES CITYkeys* KPI assessment provides a starting point for achieving a Smart City, whereas the literature review approach provides perspective, for a more in-depth look at the relationship between smart city initiatives and environmental sustainability.

It is ironic that the City of Tshwane states to become a Smart City, as there is no existing central data platform and in certain sectors there are not even existing data due to lack of monitoring and evaluation. It was found, in order to improve the above assessment on the level of City of Tshwane it is vital to develop a centralised data publishing, safe keeping and management system for the purpose of exploiting and localising current available city data. Although, being within a developing country and challenged with numerous constraints, the City of Tshwane has a very long road ahead to achieve this type of transformation (SACN, 2016).

In order to achieve the abovementioned environmental principles, by developing as a Smart City that contributes successfully towards environmental sustainability, a rigorous assessment and reporting mechanism is recommended to support city decision-making. Ultimately it was realised that there is a strong relationship between smart city

implementations and the improvement of environmental sustainability, from international examples. Environmental sustainability has the potential to be greatly transformed by smart city technologies and actions (Bakker & Ritts, 2018). The current urban development movement should motivate urban managers, environmental planners, and academics to identify innovative methods to encourage urban and socio-economic growth with the minimal environmental effect and sustainable natural resources use.

The research objectives have been described, assessed and achieved successfully during the course of the research study. Application of the *CITYkeys* indicator framework in practice has the potential to promote the rapid widespread adoption and implementation of smart city services and solutions in order to achieve sustainable environmental goals within the urban space of the City of Tshwane. During the literature review approach research objectives have also been successfully achieved. The relationship between key smart city indicators and environmental sustainability, which could be applied to measure progress and achieving policy objectives, have been established. Accordingly, the overall objective has been achieved to plan and recommend the most appropriate city environment that can foster the dynamic interactions necessary to implement sustainable and adaptable smart city projects for the purpose of enhancing the quality of the natural environment.

In conclusion, the study was conducted due to the increasing interest in the subject of smart cities and environmental sustainability, from the year 2013 (Brilhante & Klaas, 2018). The results have led to the establishment of a smart environmental sustainable city concept and an evaluation tool to be applied during policymaking and academic activities, for the purpose of supporting cities to become more environmentally aware and concerned with preservation. Furthermore, a renewed interest to provide better and innovative city services was realised, due to decades of limited change in the Tshwane Metropolitan region. We can no longer ignore the environmental problems after years of increasing urban consumption and severe constraints on the citizen's wellbeing. Key findings of the research project were based on a specific pillar of the three pillars of the sustainability theory, being the environment and includes energy, social wellbeing, infrastructure, density, urban planning, climate change, land distribution, and greenery (Fu & Zhang, 2017). To answer the research questions, it is evident that smart city initiatives applied in all city activities facilitate the progress of resource efficiency within a city. Consequently, contributing towards enhancing the environmental performance, quality, liveability and sustainability within the city. In order to achieve this, the Smart City level of a city needs to be measured and evaluated to establish a baseline supported by existing data to best inform an integrated approach in environmental planning and implementation procedures (Huovila, et al., 2017).

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APPENDICES

APPENDIX A: Detailed description of *CITYkeys* indicators for City of Tshwane

Social Indicators
Access to services

Access to public transport		
Indicator Justification	Increased availability of public transport modes to private motor vehicles leads to a decrease of motors on the road, which in turn contributes towards a more green, healthy and accessible city. It also contributes towards achieving policy goals for transport development and sustainable mobility. Once access is promoted and increased to public transport, as a result use of the transport mode is increased.	
Calculation	The number of bus stops provided by the city authorities, divided by the city area, and multiplied by a 100.	
Opportunities and Limitation	**(+)** An absolute measure is provided by the indicator concerning public transport and the ease of access. **(-)** By only making an allowance for the physical catchment areas as an absolute measure, other significant data could be excluded concerning the quality of mobility (i.e. intermodal integration, reliability, attractiveness, and comfort). Access to sustainable modes of transport is not the only factor that guarantees use (i.e. perceptions of practicality, safety, convenience, cost, and comfort). Only the provided quantity of the service was considered, not including primary destination stops or quality. Therefore, results may be distorted relating to the current state.	
Data Attained	Data source	The city software and a desktop study were utilised.
	Collection interval	Yearly
	Accessibility	Data on transport stop locations are public Information.

Length of bike route network		
Indicator Justification	A transport system that encourages the use of bicycles secure numerous benefits due to the decrease in traffic congestion and improvements on the wellbeing of citizens (ISO/DIS 37120, 2013). Also bicycle lanes require a smaller amount of infrastructure investments versus alternative modes of transport. The indicator delivers a valuable measurement tool of diversified transport systems of cities.	
Calculation	The length of bicycle paths or lanes in comparison to the international standard. Results indicated as % in km.	
Opportunities and Limitation	**(+)** Indicates the physical availability of infrastructure implemented for cycling in comparison to motor infrastructure, the mode of transport we strive to replace. **(-)** The geographical terrain and bike route quality may be deceptive, with regards to safety, quality and usability.	
Data Attained	Data source	The department of traffic and data was also available on the City of Tshwane website, including the Tshwane Comprehensive Integrated Transport Plan (2014).
	Collection interval	Yearly
	Accessibility	The available information is not sensitive and is accessible to the public.

Access to free public Wi-Fi	
Indicator Justification	The internet functions as a significant enabler. Mainly for sharing information and providing private and public services online. Chalmers (2013) states that broadband speed contributes toward increasing economic development, both on a macro and micro scale. The indicator intends to promote good city connectivity. Internet access also promotes remote working spaces and further reduces motor vehicles on the road. Public Wi-Fi coverage has proven to improve the reputation and also the attractiveness of a city. Furthermore, Wi-Fi coverage links different actuators, sensors, and additional devices to the fibre optics network running throughout the city. Providing connective pathways and making the city smarter.

Calculation	Implemented Wi-Fi connections throughout the City of Tshwane, calculated as the number of Wi-Fi nodes/ Total city urban surface*100% (% of km^2).	
Opportunities and Limitation	**(+)** The indicator measures the real availability of public internet and increases comparability to other smart cities. **(-)** Additional characteristics such as availability, affordability of devices, etc. are excluded from the measurement.	
Data Attained	Data source	Sources include maps of publicly owned Wi-Fi nodes affiliated with government censuses, the city government and official estimates. It was further found that SACN reports included valuable figures.
	Collection interval	Yearly
	Accessibility	The indicator provides for public Wi-Fi hotspots, therefore data is open to the public.

Safety and wellbeing

Crime rate	
Indicator Justification	The quantity of annoyances, crimes and violence indicates primarily the feeling of personal safety in a society (ISO/DIS 37120, 2013).
Calculation	The result is indicated as the number of crimes per 100 000 population. The indicator is calculated as the total figure of all crimes/ one 100 000th of the city's total population (Only reported crimes could be considered.)
Opportunities and Limitation	**(+)** Crime rates could be defined and assessed to implement relevant smart city initiatives accordingly. **(-)** Not all crimes are reported and local law reinforces are challenged with major backlogs and corruption.

Data Attained	Data source	Government local websites, census and city police departments, in addition to the Development Information & GIS Department.
	Collection interval	Yearly
	Accessibility	Crime rates are public information

Fatal traffic accidents		
Indicator Justification	The indicator provides a measurement for the general safety of a transport system, its congestion, and the complexity of the transport network and roadway. Furthermore, traffic law enforcement effectiveness, the public and private transportation fleet quality, and road conditions are indicated (ISO/DIS 37120, 2013).	
Calculation	The result is indicated as the # /100,000. Calculated as the number of fatalities related to transport/ one 100 000th of the total city population	
Opportunities and Limitation	**(+)** An absolute and objective value is provided by the indicator. **(-)** Not all traffic incidences could be taken into account, for example not all are reported.	
Data Attained	Data source	Government local websites, census and city police departments. In addition to the Comprehensive Integrated Transport Plan.
	Collection interval	Yearly
	Accessibility	Crime rates are public information

Access to basic healthcare	
Indicator Justification	All aspects of life require good health as a foundation to prosper and the adequate access to health is required for the functioning and overall wellbeing of society.

Calculation	(population with access to various health care services <5km/total city population)*100. Result expressed as % of people.	
Opportunities and Limitation	**(+)** An absolute measure is provided by the indicator for the ease of access to public health. **(-)** The social (i.e. affordability of services) and cultural (i.e. language) barriers are not taken into account, thus the entire picture is not indicated. Only the physical dimension of accessibility is measured. Quality of healthcare services is not taken into consideration, which has a great impact on patient care.	
Data Attained	Data source	The city software and a desktop study were utilised. Maps of the city area were used to locate public health centres, to draw 5km access perimeter circles around them and to utilise available city resident data. City administration documents were used for analysis.
	Collection interval	Yearly
	Accessibility	Data on the location of health care services are public material.

Education

Environmental education	
Indicator Justification	To enhance support for environmental programs and projects it is essential to create awareness of environmental problems, especially at school level. After all, children are the next generation who will be looking after our planet's environmental integrity. This indicator therefore evaluates to what extent education programs, relating to sustainability and the environment, have been applied at educational facilities.

Calculation	The number of schools with environmental education programs (numerator) divided by the total quantity of schools (denominator) and multiplied by a 100. The result is expressed as % of schools.	
Opportunities and Limitation	**(+)**Enhancing support for environmental programs and projects is essential to create awareness of environmental problems, especially at school level. **(-)** Environmental education is a wide-ranging concept and is interpreted and implemented on various levels with various standards.	
Data Attained	Data source	City administration documentation and online school reports.
	Collection interval	Yearly
	Accessibility	Educational program data is public information.

Digital literacy and ICT		
Indicator Justification	Digital competency is the critical, confident and creative utilisation of ICT to achieve certain objectives. The ECDL foundation (2009) states that digital literacy is an important element in enhancing overall development within an economy and a society. However today, within the City of Tshwane a digital divide persists. The four leading elements of the digital divide are associated with the City of Tshwane, which includes affordability, access, skills and relevance of content (ECDL, 2009).	
Calculation	(Amount of people reached/ Amount of people in study area)*100% Result is expressed as % of people.	
Opportunities and Limitation	**(+)** ICT adoption is indicated, which shows the local movement towards implementing smart city projects. **(-)** The definite increase of digital literacy is excluded and the research is limited to the national sphere of the City of Tshwane.	
Data Attained	Data source	The data was unavailable from documents relating to implementations that have taken place within the city, (i.e. organisations providing training, schools and the city administration). Thus, information was derived from national data, including that of the Internet World Statistics group.

	Collection interval	Yearly
	Accessibility	Data was considered unattainable on a city level; therefore national data sources were utilised.

Quality of housing and built environment

Green public space		
Indicator Justification	Green public spaces are necessary within a cityscape and contribute towards citizen health, community participation and the vitality of a city. Green public spaces are provided by cities as a service through parks, recreation departments and other related offices. Most importantly, green spaces perform significant environmental functions in the setting of a city. For example, improving the urban climate, the caption of atmospheric pollutants and improving the wellbeing of city residents (ISO/DIS 37120, 2013).	
Calculation	Green public space is calculated as (ISO/DIS 37120, 2013); the total area (m^2) of green in the city/ total population of the city Results are indicated as m^2/ person	
Opportunities and Limitation	**(+)** This is a firm and objective value indicator. **(-)** The considered green recreational space only included city-owned or maintained land. Furthermore, the environmental and recreational quality of the spaces is not taken into consideration.	
Data Attained	Data source	Data was attained from the City Planning Department, in combination through the use of aerial photography and land use maps to delineate green recreation spaces. Online systems and Google Earth was used to calculate and measure the green recreation spaces.
	Collection interval	Yearly
	Accessibility	Data on public green spaces are indicated in development plans, which are available to the public.

Environmental Indicators

Environmental performance		
Indicator Justification	The indicator is an environmental sustainability parameter, according to the WHO minimum standard. Elgazzar and El-Gazzar (2017) state that the model of a smart city is interconnected with that of a Green City, Sustainable City or Eco-city, indicating the strong linkage between the Smart City movement and improving the environmental performance of an urban area.	
Calculation	Application of data from 2011 Africa Green City Index.	
Opportunities and Limitation	**(+)**The Green City Index is a local standard and applicable to measure the City of Tshwane's environmental performance. **(-)** The use of secondary data needs to be validated with further studies, to increase reliability. The data source is outdated and more recent studies need to be conducted for results.	
Data Attained	Data source	2011 Africa Green City Index
	Collection interval	Yearly
	Accessibility	Open data portal available to the public.

Energy and Mitigation

Energy consumption	
Indicator Justification	Reducing the energy supply creates substantial savings and enhances energy supply security, whilst reducing greenhouse gas emissions. Reducing greenhouse gas emissions contributes towards fighting climate change and achieving a low to zero carbon economy. Therefore it is necessary to measure and evaluate these levels to identify reduction strategies. The indicator assesses various forms of

	energy as the final energy consumption of the city.	
Calculation	Energy consumption is calculated according to customers and sales per economic activity by a licensee. The total city usage of final energy (MWh)/ the sum of customers Results indicated as MWh/cap.	
Opportunities and Limitation	**(+)** The relevance of the indicator is high due to current policy and environmental objectives. **(-)** Data and figures are dispersed and need to be converted into a single value. The different types of energy consumption vary according to the reliability of the information. For most uses, indirect data collection methods were applied to accumulate information for the indicator results. Therefore the figures and results are estimations.	
Data Attained	Data source	The information has been attained from various sources from a range of sectors, including the Sustainable Energy Africa (2015) report.
	Collection interval	Yearly
	Accessibility	Dependant on the sources from which the data was gathered.

Renewable energy generated by the city	
Indicator Justification	Internationally, the overall benefits for shifting towards renewable energy relating to environmental and climate change benefits, in the heat, transport and electricity production industry, leads to importing independence and a certain amount of resource security. The indicator result is the proportion of the total energy resulting from renewable systems installed within the city as a portion of the total energy consumption of the city.
Calculation	The portion of renewable energy generated within the city is calculated as the following;

	Total consumption of electricity produced from renewable sources/ Total energy consumption The indicator is multiplied by a 100 and indicated as a percentage (ISO/DIS 37120, 2013). Renewables represented as % of MWh.	
Opportunities and Limitation	**(+)** The measurement is significantly applicable for evaluating the realisation of a city's renewable energy objectives. **(-)** The energy that is imported is not indicated, therefore the real share of renewable consumed energy could be higher.	
Data Attained	Data source	Information is attainable from local utility providers, city environment and energy offices, also from different international sources for example, the International Energy Agency (IEA), and the World Bank. (ISO/DIS 37120, 2013). In addition to reports compiled by NERSA (2014) and the South African Cities Network (2014)
	Collection interval	Yearly
	Accessibility	Private household energy generation is more challenging to measure, however alternative sources were available.

Emissions of CO_2	
Indicator Justification	Our world is increasingly being constrained by carbon and South Africa is already facing climate change impacts and therefore need to reduce the intensity of greenhouse gas emissions. Carbon Dioxide accounts for a great part of greenhouse gas emissions in cities. This indicator is thus useful to evaluate the contributions made by urban development towards climate change.
Calculation	The CO_2 emissions assessed in tonnes per capita measured as; The total amount of direct CO_2 emissions in tonnes (produced in a calendar year by all city activities)/ The total city population

Opportunities and Limitation	**(+)**The indicator briefly indicates the adverse impact the city makes towards climate change and how this should be prioritised when smart city initiatives are implemented. **(-)** Not all greenhouse gas emission sources are taken into account and figures obtained are estimations due to indirect data collection methods.	
Data Attained	Data source	Documents from the municipal statistical department and local greenhouse gas inventories.
	Collection interval	Yearly
	Accessibility	Dependant on the sources from which the data was gathered. Also, the quality of data had to be validated by means of repetition.

Total electric vehicle charging stations		
Indicator Justification	The portion of participating electric car owners in the study area all contribute towards reducing automotive produced pollutants. Therefore, having a positive impact on combating climate change.	
Calculation	# electric vehicle charging stations	
Opportunities and Limitation	**(+)** The indicator provides the benefit of identifying sectors where these services could be implemented and promoted to increase use. **(-)** The indicator excludes the use of e-car rental schemes and e-bikes usage.	
Data Attained	Data source	Site visits and statistics from local authority documents. Most of the data was attained from projects and reports on implementations that have previously taken place within the city.
	Collection interval	Yearly
	Accessibility	Relatively good.

Materials, land and water

Domestically consumed material		
Indicator Justification	The indicator takes into account domestic material extraction. In other words, the number of raw materials removed from the natural environment, excluding air and water. The consumption of resources and materials affects the environment and contributes toward depletion of resources if this is done unsustainably. Thus, sustainability benefits are derived from reducing consumption levels, along with consequent impacts.	
Calculation	The total quantity of material used directly per capita in the city. Results are expressed as t/cap/year. Domestic material consumption = (Direct material input – exports)	
Opportunities and Limitation	**(+)** Improving consumption levels have positive effects on the economy and protects the environment. The manufacturing of more materials also increases the energy demand and consumption, which in turn increases emissions. The assessment therefore contributes to the decrease of numerous factors that negatively affect the environment. **(-)** Data availability is locally a challenge due to the lack of valid information and records. Also, materials have different characteristics for various functions, thus the quality and weight of the function could be debated.	
Data Attained	Data source	A material flow analysis on the City of Tshwane from private and public organisations, including the Africa Sustainable Development Report (2018).
	Collection interval	Ad hoc
	Accessibility	Availability of data was low and access depended on data sources.

Water consumption	
Indicator Justification	Water consumption is sustainable when it is in co-ordination with water sources available (ISO/DIS 37120, 2013). Water management and security of potable water is a global issue. The indicator should be measured in terms of changes on a yearly basis within a city.

Calculation	The total amount of water consumption in the city in litres daily (numerator) divided by the city population total (denominator). Results expressed as litres/cap/year.	
Opportunities and Limitation	**(+)** The indicator shows progress in water-saving practises and alterations in consumer behaviour. **(-)** In a municipality, the variance between the total usage of ground and surface water and the volume of released water in the distribution networks are not interconnected with the local water supply system. This is due to the use of water by individual households and other role players.	
Data Attained	Data source	Data on the 'Total use of water' is indicated in the urban audit database. Further data was collected from sectors that provide the service.
	Collection interval	Yearly
	Accessibility	Dependent on local supply authorities.

Water losses	
Indicator Justification	A part of the water supplied is lost before reaching the end-user, through illegal tapping or leakage. Local cities have unmaintained, deteriorating and old water reticulation structures, where a considerable amount of piped water is lost. It should thus be measured to indicate priority for improvement.
Calculation	$\frac{(\text{Supplied volume of water} - \text{Water volume of customer's billed})}{\text{Total water volume supplied}}$
Opportunities and Limitation	**(+)** High relevance with regards to environmental sustainability and policy aims. **(-)** The different kinds of water losses are not accounted for. Obvious losses are measured by metering, therefore monitoring, management and human errors could occur. For the purpose of this study focus is placed on pipe system leakages, where water is wasted.

Data Attained	Data source	Data was attained from servicing water utilities and the City of Tshwane Water Services Development Plan (2017).
	Collection interval	Yearly
	Accessibility	Dependent on local supply authorities, but no data sensitivity.

Population density		
Indicator Justification	The indicator relates to numerous features of sustainable urban development. For instance, the effectiveness and efficiency of urban infrastructure operations, the portion of green transport modes, citizen wellbeing or a city's ecological footprint.	
Calculation	Total number of city residents/ Total area of the city (km^2)	
Opportunities and Limitation	**(+)** The calculation is not complex and the indicator is objective and absolute. **(-)** The indicator has no direct connection with sustainability or smartness.	
Data Attained	Data source	City statistics, backed by international research indicators. International data on local circumstances were more recent.
	Collection interval	Yearly
	Accessibility	Public data is accessible.

Food production locally	
Indicator Justification	Local food production affects the urban area's carbon footprint, by influencing energy consumption or required transport or economic growth. Local food production increases resilient and self-sufficient food networks and enhances local economies in urban geographical areas
Calculation	(Food manufactured in 100km radius (tonnes) / Total city food demand (tonnes)) * 100 Results expressed as % of tonnes.

Opportunities and Limitation	**(+)** The indicator is a good measure to provide an overview of the city's possible self-sufficiency options. **(-)** Comparability issues arise concerning data on the agricultural yield.	
Data Attained	Data source	City statistics and the South African Cities Network: Urban Food Security Report (2015).
	Collection interval	Yearly
	Accessibility	Accessibility is good for public data.

Brownfield use		
Indicator Justification	"Brownfield" is a term utilised by town planners to define "land which is or was occupied by a permanent structure, including the curtilage of the developed land and any associated fixed surface infrastructure" (Department for Communities and Local Government, 2012, p. 2-4). Brownfield development and regeneration present valuable opportunities, to not only preserve natural environmental spaces from being developed but also to improve urban spaces (DG Environment, 2013).	
Calculation	Redeveloped brownfield area from past year (km^2)/ City total brownfield area (km^2) Results indicated as % of km^2.	
Opportunities and Limitation	**(+)**The calculation is not complex and high relevance concerning environmental sustainability and policy aims. **(-)** Limited comparability due to different understandings of the term "brownfield". Monitoring of data is considered irrelevant in the City of Tshwane and is disregarded (SACN, 2016).	
Data Attained	Data source	Data was unavailable; however an extensive search was conducted in the following databases; City of Tshwane, Urban Planning Department, city officials, BEPP, SACN, ResearchGate, Cities100, SDF (2018), IDP (2019), and the Tshwane Compaction and Densification Strategy.
	Collection interval	Per annum

	Accessibility	Access to data was limited to employees of planning departments and city administration. Alternative resources indicated that there is no measurement in place to monitor various brownfield development sites from different sectors in the past year.

Pollution and Waste

Nitrogen oxide emissions (NOx) data availability		
Indicator Justification	The European Innovation Partnership on Smart Cities and Communities (EIP SCC) identified that improving the air quality of cities should be prioritised. Nitrogen oxides are main air pollutants, which could have severe effects on the environment and human health, therefore it is of utmost importance to be specifically monitored for data generation (ISO/DIS 37120, 2013).	
Calculation	Average percentage of data availability from five monitoring stations.	
Opportunities and Limitation	**(+)** Important indicator related to transport, domestic heating and industrial processes. **(-)** Double counting with energy indicators could occur.	
Data Attained	Data source	City statistics from monitoring stations and Environmental department offices.
	Collection interval	Annually
	Accessibility	Some access to data is restricted to employees of the department or only city administration.

Air quality index	
Indicator Justification	The European Innovation Partnership on Smart Cities and Communities (EIP SCC) identified that improving the air quality in cities should be prioritised as a challenge. Air quality is specified as the concentration of main air pollutants. The year average air quality index was used for this indicator.

Calculation	For each pollutant, an objective value is provided according to the scheme created by the *CITYkeys* report. If the index is below 1: the target values are met on average. If the index is greater than 1: for one or more pollutants the objective values are not reached.	
Opportunities and Limitation	**(+)** Important indicator related to policy aims and climate change resilience strategies. **(-)** For most uses, indirect data collection methods were applied to obtain figures for the indicator calculation. Therefore the information attained and calculated are estimations.	
Data Attained	Data source	In some cases monitoring equipment measure concentrations, and is reported to the Air Quality monitoring authorities. Data was used from the City of Tshwane's national or local variant of an air quality index, which replaced the *CITYkeys* indicator of the target value scheme.
	Collection interval	Annually
	Accessibility	Some access to data is limited to employees of the environmental department or city administration.

Municipal solid waste		
Indicator Justification	One of the most significant elements of the wellbeing in a city is the appropriate transportation, treatment, and discharge of solid waste. This indicator measures the quantity of waste produced within the city and the standard of services a city provides for its collection (ISO/DIS 37120, 2013). The data only refers to municipal waste managed by local authorities.	
Calculation	Total amount of solid waste (commercial and household) produced in tonnes/ Total population of the city Result indicated as t/cap/yr.	
Opportunities and Limitation	**(+)** The indicator is an absolute value that is understandable and measurable. **(-)** Data of city authorities should be up to date and standardised, for results to be more reliable.	
Data Attained	Data source	Information was expected to be obtained from the department responsible for waste collection and the

		environmental department however, the SACN Programme on Waste Management (2014) had more reliable figures.
	Collection interval	Annually
	Accessibility	Data and public reports are allowed to be requested by the public.

Recycling rate		
Indicator Justification	Greater environmental challenges are created by higher levels of municipal waste, thus levels of collection and removal of municipal waste are vital components of managing the environment. The life cycle of landfills could be maximized by proper solid waste systems that have adopted recycling practices, also recycling microeconomics are created. Recycling provides alternative sources of energy generation that reduces fossil fuel and electricity consumption.	
Calculation	The city's total amount of solid waste that is recycled (tonnes)/ The city's total amount of solid waste generated (tonnes) Result expressed as % of tonnes.	
Opportunities and Limitation	**(+)**The indicator is a clear unit that is understandable and measurable. **(-)**Data of city authorities should be up to date and standard, for results to be more reliable.	
Data Attained	Data source	Data attained from public services, municipal bodies, and private contractors that provide the services of solid waste disposal and collection. Information was further verified through research studies conducted on solid waste for the specific project of the SACN Programme: Waste Management (2014).
	Collection interval	Yearly
	Accessibility	Good

Ecosystem

Share of water and green spaces		
Indicator Justification	Blue and green regions are considered as an index that represents the level of improving the wellbeing of urban citizens and nature conservation because these spaces are directly linked to environmental purification, public health, green networks and natural water circulation. The indicator shows the ratio of green and water space area in relation to the total city land area. Green spaces include park areas and forests, therefore those covered with vegetation. Water spaces include rivers, catchment areas, lakes and ponds.	
Calculation	$$Share\ of\ blue\ and\ green\ spaces\ [\%] = \frac{\text{water area}\ [\text{km}^2] + green\ area\ [\text{km}^2]}{\text{Total city land area}\ [\text{km}^2]} \text{ x } 100$$	
Opportunities and Limitation	**(+)** The indicator assesses to what extent natural conservation and natural areas need to be preserved and protected within urban spaces. **(-)** Different types of natural and water areas exist within a city, therefore this should be kept in mind when measuring the spaces to not leave out those that are relevant.	
Data Attained	Data source	Data were retrieved from the Environmental Affairs Department of the city. In addition, city maps were used to estimate surface areas from the Protected Areas Register Esri Map Tool. The City surface was retrieved from the World Population Review, which had the most recent figures.
	Collection interval	Yearly
	Accessibility	Public information

Threatened species	
Indicator Justification	Urbanisation has an impact on biodiversity due to urban sprawl, degradation of fruitful agricultural lands, habitat fragmentation, and spreading invasive species (ISO/DS 37120, 2013). The number of priority threatened species in the Bioregion indicates to which extent protective measures need to be implemented. Species are classified as Critically Endangered, Endangered, Vulnerable and Extinct, of which are plant, mammal, bird and invertebrates species.

Calculation	Number of priority threatened species in the Bioregion. Results expressed as # of species.	
Opportunities and Limitation	**(+)** Opportunities arise when evaluating biodiversity loss because consequential issues could thus also be addressed. Such as threatened food supplies, decreased availability of energy sources, lessened diversity within medicinal sources, and a decrease in recreational and tourism opportunities. The indicator is essential to minimise urban interferences with ecological functions. **(-)** The use of secondary data needs to be validated with further studies, to increase reliability. Additionally, the indicator does not account for the conditions the species live in or their state of health, only their presence.	
Data Attained	Data source	Information was retrieved from government agencies managing biodiversity, such as city municipalities, biodiversity centres, forestry city departments, urban planning agencies, nature groups, and universities.
	Collection interval	Yearly
	Accessibility	Public information and no sensitive data.

Green economies

Certified companies	
Indicator Justification	Increasingly, organisations systematically have been prioritising environmental aspects of their business. For those companies that are going the extra mile and are operating beyond only complying with regulations and rules, have the ISO 14000 series of standards as a guide for environmental management. It is assumed that if a city has a significantly great level of certified companies that environmental quality and sustainability is locally advanced.
Calculation	$\frac{Amount\ of\ companies\ with\ recorded\ ISO\ 140001\ certificates}{\text{Total amount of registered companies within the country}}$ x 100

Opportunities and Limitation	**(+)** The calculation is not complex and high in relevance concerning environmental sustainability and the City of Tshwane's policy aims. This indicator relates to local environmental quality and its sustainability within a city. **(-)** A minority of companies are certified, and those not certified could also be conducting their business in an environmentally sound manner. An amount of certain subjectivity cannot be avoided concerning this indicator, due to various related definitions and existing certification systems. The relevant data is unavailable on a city level regarding City of Tshwane, data is thus presented on a national level.	
Data Attained	Data source	Data was attained from the ISO survey registers and business registers on a national level.
	Collection interval	Yearly
	Accessibility	Good, due to the fact that companies use this information to promote the company.

Green jobs	
Indicator Justification	Job opportunities are created through the process of 'greening the economy', in sectors directly linked to the environment. The *CITYkeys* report states that it is expected of a Smart City to show a significant increase in green jobs (Bosch, et al., 2017, p. 271). The UNEP (2008) describes a 'green job' as the following - "*work in environmental service activities that contribute substantially to preserving or restoring environmental quality. Specifically, but not exclusively, this includes jobs that help to protect ecosystems and biodiversity; reduce energy, materials, and water consumption through high efficiency strategies; de-carbonize the economy; and minimize or altogether avoid generation of all forms of waste and pollution."*
Calculation	Sum of green jobs divided by the total sum of jobs, multiplied by a 100.
Opportunities and Limitation	**(+)** The indicator assesses if it is necessary to promote job creation in sectors directly related to the environment and also the relationship between environmental performance and job creation is presented.

	(-) Data collection is complex, because uncertainty arises when environmental protection expenditures are compared to actual job creation. Therefore, funds spent to conserve the environment might be overvalued compared to green jobs.	
Data Attained	Data source	Green jobs are not accounted for separately, concerning the City of Tshwane statistics. Statistical data was thus used on environmental protection expenditures to estimate the number of green jobs. The figures were further justified through the analysis of the Green Jobs document (2011), which is an estimate of the potential to green the South African economy through direct employment.
	Collection interval	Annually
	Accessibility	Accessibility level is low and estimations were searched in available documented reports.

Amount of Green Public Procurement	
Indicator Justification	The indicator assesses the percentage annual procurement as a portion of the total annual procurement of the city authorities, using environmental criteria. The indicator further assesses the purchasing power of a city to decide on environmentally friendly services, works and goods, to identify if the city is making a positive contribution towards sustainable production and consumption. Green Public Procurement is thus a robust stimulus for eco-innovation.
Calculation	$\frac{\text{City yearly procurement by means of environmental criteria (Million)}}{\text{Total procurement of city authorities (Million)}}$ x 100 Result indicated as % in Rand.
Opportunities and Limitation	**(+)** The calculation is not complex and high in relevance concerning environmental sustainability and policy aims. **(-)** Data availability is locally limited and while one could use green labels as an indicator, it does not provide the full picture. Furthermore, the definition of Green Public Procurement is not rigid.

Data Attained	Data source	The corporate facilities department of the city, but data is limited to its own sustainable purchasing. Therefore, information was further gathered from different department reports for example, the 2019/20 Medium Term Revenue and Expenditure Framework for the City of Tshwane (2019).
	Collection interval	Term
	Accessibility	No sensitivities are linked to information, however reliability of city figures are questionable.

Innovation

Innovation hubs		
Indicator Justification	The number of innovation hubs indicates the development and expansion of intellectual skills and capital within a city. High performing innovation hubs create connections between fields and sectors of development, which previously might not have existed. Therefore positively impacting the socio-economic development of an area. The indicator includes the physical co-working space for knowledge, businesses, government and institutional parties.	
Calculation	Number of innovation hubs in the city, result expressed as #.	
Opportunities and Limitation	**(+)** The indicator exposes the importance of creating value in the development of knowledge. **(-)** The number of facilities does not take into account the standard of these facilities, which could influence the performance quality of the institutions.	
Data Attained	Data source	Reports from tertiary institutions and alternative research institutes, including city government data.
	Collection interval	Annually
	Accessibility	No sensitivities linked to data.

Accessibility of open datasets

Indicator Justification	Public access to city data is a very important element of a Smart City and open city datasets create value in certain sectors. For example public participation, innovation, improved efficiency, the effectiveness of governmental services and self-empowerment. Assessing the standard of city open datasets is significant to support the simplicity of use and the availability of information.	
Calculation	The total number of datasets accessible for public use. Results expressed as # of datasets.	
Opportunities and Limitation	**(+)** Access to open datasets is a very important element of a Smart City and open city data creates value in certain areas. Development of public knowledge is promoted, making people less dependent. **(-)** To a certain extent, subjectivity cannot be avoided. Quality of data is not expressed through the indicator according to accuracy, credibility, relevance, consistency, completion, or according to time.	
Data Attained	Data source	A list of open datasets from the local government website, which is specifically applicable to the City, was considered. Also, the amount of City datasets available through the search engine; Google Results.
	Collection interval	Annually
	Accessibility	Reliable datasets are difficult to trace and there is no existing core platform for all relevant city data, therefore the information is scattered.

Research intensity	
Indicator Justification	Frascati Manual (2002) expresses research and development (R&D) as - *"the creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications".* Internationally, gross domestic spending on R&D is the main aggregate to assess R&D levels. The indicator evaluates the total spending on R&D by all relevant stakeholder, defined as a percentage of the city gross domestic spending.
Calculation	(Total R&D expenditure/ City's GDP)*100 Results expressed as % in Rand.

Opportunities and Limitation	**(+)** The indicator is an absolute value that is understandable and measurable. **(-)** Locally, it is more complicated to gather data specific to the urban area, therefore it is measured on a regional level. Funding could also come from different sources therefore results are estimations.	
Data Attained	Data source	The gross domestic product was applied and the expenditures on R&D requested from the municipal Economics Department. Further validation of figures was established according to the recent results captured in the IHS Global Insight document (2017).
	Collection interval	Annually
	Accessibility	For a large part of the data there are no sensitivities.